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DEPARTMENT OF THE ARMY

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BREAKWATER LOCATION
U. S. NAVAL AIR STATION, ALAMEDA, CALIFORNIA

MODEL INVESTIGATION



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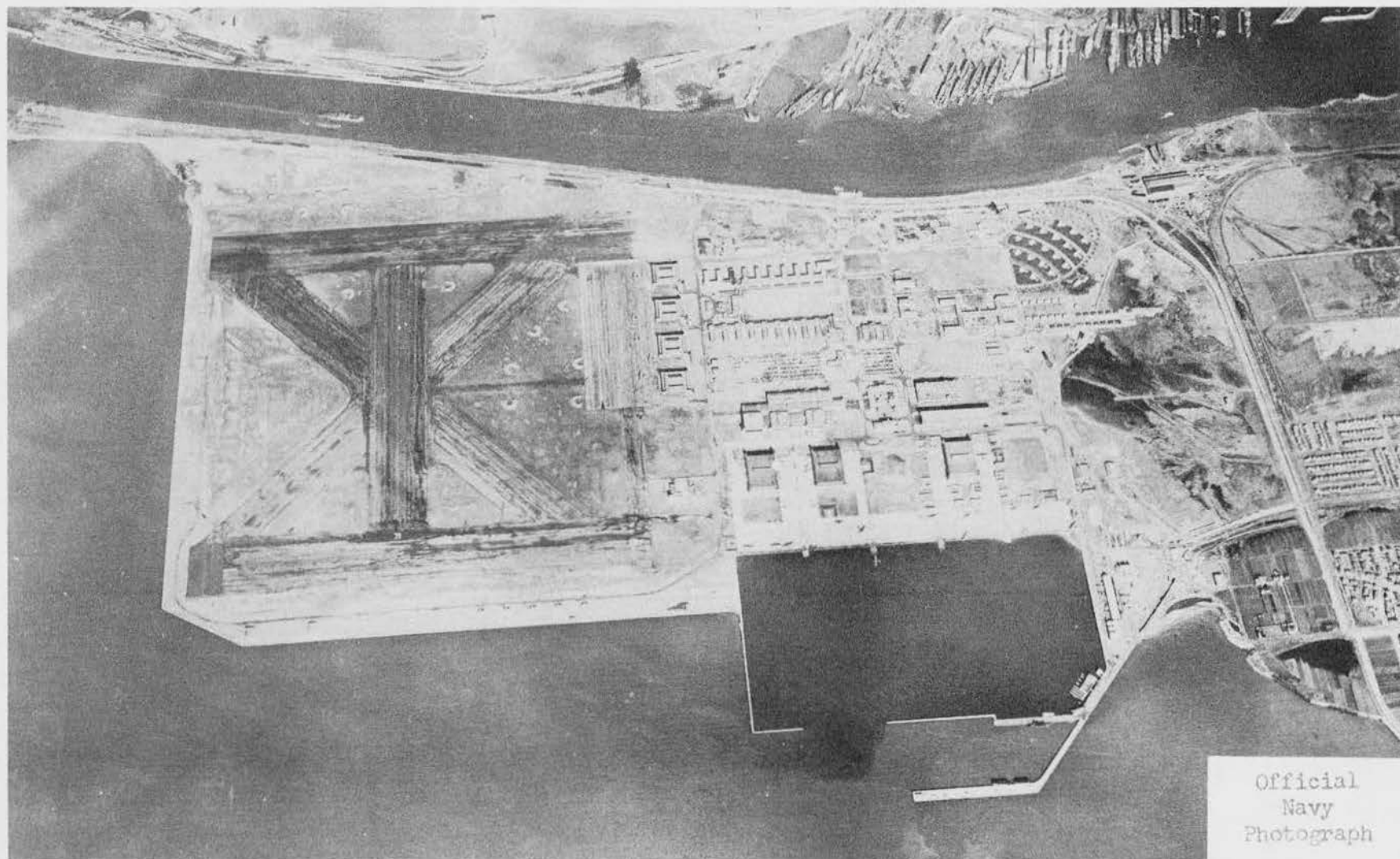
WATERWAYS EXPERIMENT STATION
VICKSBURG, MISSISSIPPI

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Aerial view of Alameda Naval Air Station, January 1942, looking north.
Seaplane lagoon and carrier pier in foreground.

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BREAKWATER LOCATION

U. S. NAVAL AIR STATION, ALAMEDA, CALIFORNIA

Model Investigation

SYNOPSIS

This memorandum is a comprehensive report of a hydraulic model study of wave action at the carrier pier and in the seaplane lagoon, and of shoaling in the dredged turning basin of the U. S. Naval Air Station, Alameda, California. The investigation was performed by the Waterways Experiment Station at the request of the Chief of the Bureau of Yards and Docks, Navy Department, during the period from November 1942 to February 1945.

The Naval Air Station at Alameda is provided with facilities for both land- and sea-type aircraft and for naval ships of various types. Its location, west of the City of Alameda along an unprotected section of the shore line of San Francisco Bay, exposes the docking facilities to local storm waves from the southeast to southwest directions. There is also considerable shoaling in the dredged turning basin (located at the entrance to the lagoon and pier) from deposition of silt material.

The purpose of the model study was to investigate proposed plans for protecting the carrier pier and seaplane lagoon from storm waves, and for eliminating or reducing the shoaling in the turning basin. These plans consisted of various locations and alignments of a protecting breakwater, sizes and locations of navigation openings in the breakwater, lengths of north-south spur breakwaters on both sides of the navigation opening, and top elevations of the breakwater.

The study was conducted on a 1:200-scale model which reproduced the shore line adjacent to the Alameda Naval Air Station, the seaplane lagoon, carrier pier, entrance channel and turning basin, and a portion of the adjoining area of San Francisco Bay. It was concluded from the results of the model tests of proposed improvement plans, and from the study of prototype wave and shoaling data furnished by the Officer in Charge of Construction at the Naval Air Station, that:

- a. The causes of the problem were the local storm waves which approach the problem area from about the southwest direction, and the deposition of silt in the dredged turning basin. Evidence indicated that the silt was transported by the ebb-tide currents from the mud flats southeast of the basin.
- b. A breakwater following the general alignment of the southern limits of the turning basin would provide adequate protection from storm waves.
- c. The alignment of the shoreward arm of the breakwater is not critical with respect to wave action, and may be shifted clockwise to inclose the area designated for additional harbor works, or counterclockwise to reduce the length of breakwater, without affecting the efficiency of the breakwater in protecting against storm waves.
- d. Extending the breakwater westward parallel with the south line of the entrance channel, either with or without a spur breakwater from the landing field seawall to the entrance channel, would reduce wave heights in the problem area. The practicability of this plan is questionable, however, in view of the appreciable additional length of breakwater involved.
- e. Narrowing the navigation opening from 750 ft to 500 ft would not result in a material reduction in wave heights in the problem area.
- f. Top elevations of +12 ft mllw for the shoreward arm, and +15 ft mllw for the bayward arm of the breakwater, would adequately protect the problem area from overtopping waves.
- g. All plans tested would be effective in reducing the amount of shoaling in the problem area, although none of the plans having a navigation opening for taxiing aircraft would completely eliminate shoaling in the turning basin.

- h. The use of north-south spurs at the aircraft navigation opening would assist in reducing the amount of shoaling in the entrance channel and turning basin.

On the basis of the findings of the model investigation and practical considerations relating to the problem at the Alameda Naval Air Station, a plan designated in this report as plan 21A ^(Plate 72) was recommended for construction in the prototype. This plan consisted principally of a 6830-ft rubble-mound breakwater located immediately south of the turning basin and aligned to enclose the turning basin except for the entrance channel on the west and a 750-ft navigation opening on the south.

PART I: INTRODUCTION

The Prototype

1. The U. S. Naval Air Station at Alameda, California, is located on the east shore of San Francisco Bay, west of the City of Alameda. The Naval Air Station occupies a point of reclaimed land bounded on the north by San Antonio Estuary, on the east by Alameda, and on the south and west by San Francisco Bay. Figure 1 shows the geographical location of the Station and the extent of prototype area included in the model.

2. The Naval Air Station is equipped with docking facilities for seaplanes and for aircraft carriers and other types of naval ships. A landing field for land- and carrier-based planes is also included in the installations. Docking facilities consist of the seaplane lagoon, tender pier, and carrier pier; navigation facilities consist of the dredged entrance channel and turning basin. The landing field is protected from the bay by a rock seawall, and the seaplane lagoon is protected by a rock jetty. A 650-ft navigation opening in the jetty is provided on the south. The lagoon, about 11 acres in area, is dredged to a project depth of 12 ft below mllw. Seaplane docking ramps are located along the north shore line of the lagoon; the fill-type tender pier forms a part of the south jetty and is accessible from the lagoon and turning basin. The 1000-ft carrier pier (open pile) is about 600 ft south of the south lagoon jetty and is connected to the shore by an open-pile causeway. An entrance channel with a project width of 1000 ft is dredged from about the -35 ft

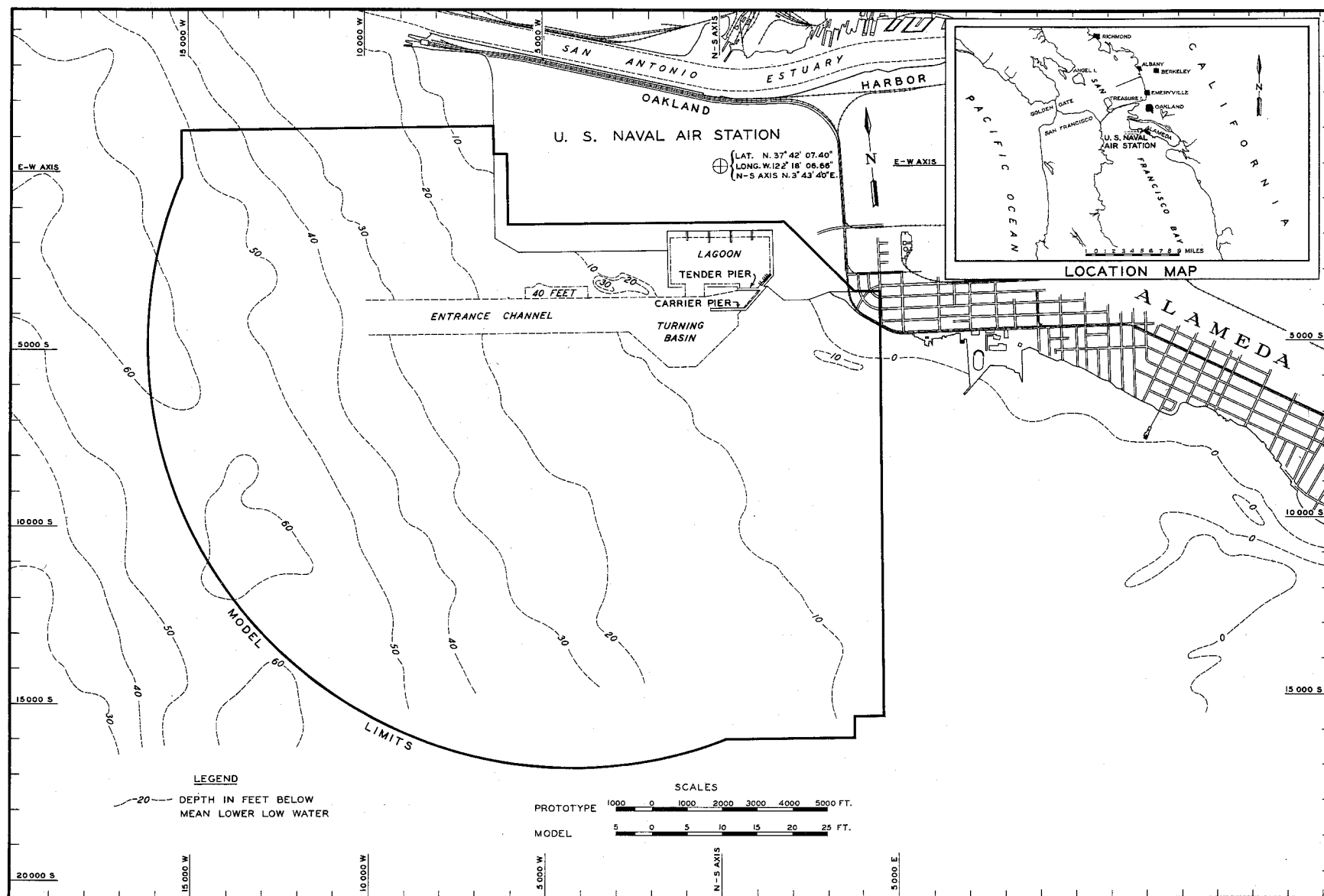


Fig. 1. Vicinity map, showing model limits

mlw contour in the bay to a 2000-ft-radius turning basin. An aerial view of the Naval Air Station, showing conditions as of January 1942, is shown on the frontispiece.

The Problem

3. The problem at Alameda was essentially to devise some practical means of providing adequate protection for the docking facilities, especially the seaplane lagoon and carrier pier, from storm waves propagated in San Francisco Bay, as well as some means of eliminating or reducing shoaling in the dredged turning basin. Storms which frequent this area of San Francisco Bay approach from the southeast to southwest directions and the effective southward fetch of the bay is such that waves are generated of sufficient magnitude to damage unprotected docking facilities and moored ships. The rate of shoaling in the dredged turning basin was such that hazardous and expensive dredging operations were necessary to maintain project dimensions. From a study of available prototype data it was decided that this rapid rate of shoaling resulted from material transported in suspension by ebb-tide flow from the mud flats located between about the -10 ft mllw contour and the shore line southeast of the Naval Air Station. Besides these existing problems, the Bureau of Yards and Docks was contemplating the construction of additional docking facilities to accommodate the heavy war-time traffic at the Station, and adequate protection for these additional facilities was also desirable.

4. In view of the existing unsatisfactory conditions and the proposed additional docking facilities, a breakwater or combination of breakwaters was proposed to protect the carrier pier and seaplane lagoon

from storm wave action and to eliminate or reduce shoaling in the dredged turning basin.

Tentative Plans of Improvement

5. A preliminary study of hydraulic characteristics of that part of San Francisco Bay adjacent to the problem area led to the belief that construction of protective works following the general alignment of the southern limits of the turning basin and entrance channel would accomplish the desired results. Accordingly, three general tentative plans of improvement were proposed: (a) a breakwater designed to protect docking facilities from southeast storms; (b) a breakwater to protect docking facilities by inclosing the turning-basin area on the southeast, south, and southwest; and (c) a breakwater to protect not only present docking facilities but also the area located adjacent to the shore south and east of the carrier pier.

Authorization of Model Study

6. The complexity of the factors involved in selection of the most satisfactory improvement plan for the Naval Air Station led to a decision to employ experimental means rather than to attempt the design of a plan by analytical methods. Consequently, it was decided that the three general types of improvement plans described above and various modifications thereto would be subjected to model analyses to determine the system of breakwaters that would be most efficacious in protecting docking facilities from storm wave action, and in eliminating or reducing shoaling in the dredged turning basin.

7. Authority for the Waterways Experiment Station to undertake the model study was requested by the Chief, Bureau of Yards and Docks, Navy Department, in a letter dated 8 September 1942, to the Chief of Engineers, U. S. Army. Authority was granted by the Chief of Engineers in a letter dated 11 September 1942. The study was conducted during the period from November 1942 to February 1945.

Liaison and Personnel

8. During the course of the model study, close liaison was maintained between the Experiment Station and the Bureau of Yards and Docks by means of: (a) progress reports submitted every two weeks; (b) interim reports on the results of each series of similar tests which were forwarded to the Chief of the Bureau of Yards and Docks immediately after completion of the tests; and (c) conferences at the Office of the Chief of the Bureau of Yards and Docks, the U. S. Naval Air Station at Alameda, California, and the Experiment Station to discuss problems relating to the model study.

9. Engineers of the Waterways Experiment Station actively connected with the study were Messrs. J. B. Tiffany, Jr., F. R. Brown, R. Y. Hudson, J. E. Arnold, A. L. Brothers, Jr., and R. A. Jackson. This report was prepared by Messrs. Jackson and Hudson.

PART II: THE MODEL

Description

10. The model was of the fixed-bed type constructed to a linear-scale ratio of 1:200 (both vertical and horizontal scales). The corresponding time and velocity scales were 1:14.14. Reproduced in the model were the shore line adjacent to the Naval Air Station, the seaplane lagoon, the carrier pier, the turning basin and entrance channel, and a sufficient area of San Francisco Bay to permit accurate reproduction of prototype wave action and tidal currents in the problem area (see figures 1 and 2).

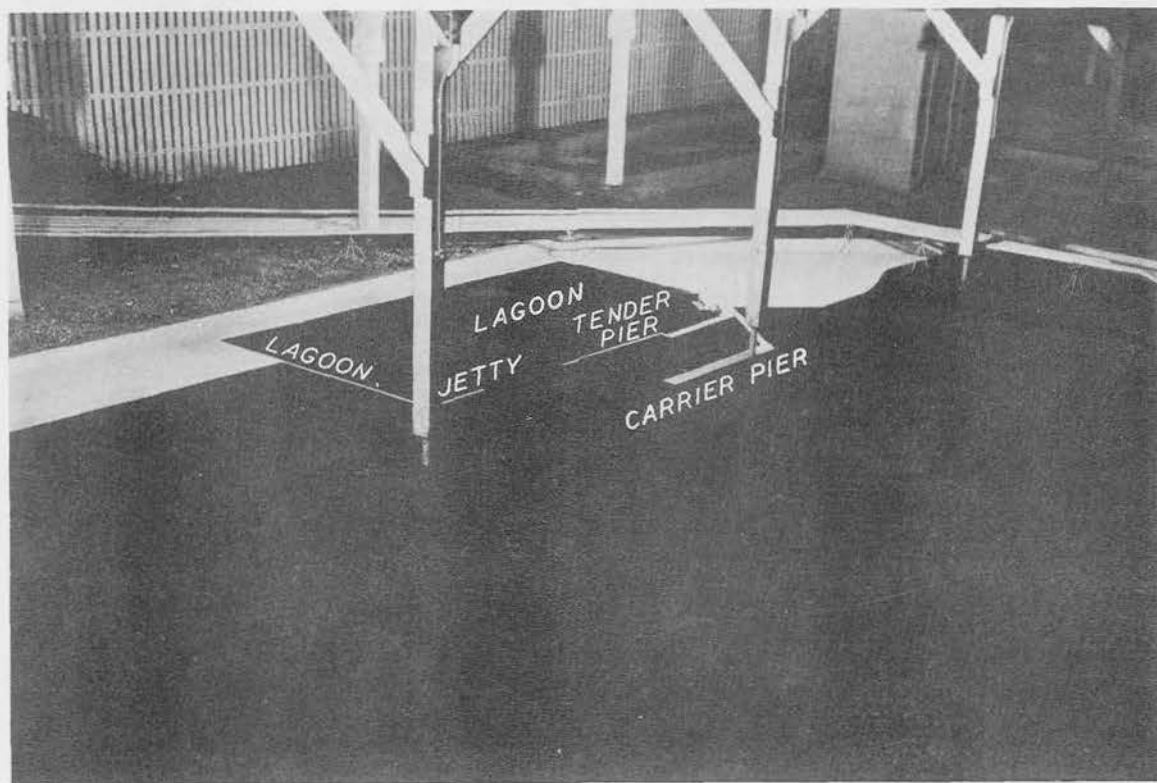


Fig. 2. General view of model representing conditions of March 1943

Wave machines

11. Prototype waves were reproduced to scale in the model by two plunger-type wave machines; figure 3 shows one of these machines. Generation of waves was accomplished by displacement of water caused by vertical movement of the plunger. Different combinations of the plunger stroke, speed, and submergence generated waves of desired characteristics. To simulate waves from different directions of approach, the wave machines were mounted on casters and placed in a circular pit in such manner that they could be moved to the proper position on the model for generating waves from the desired directions.

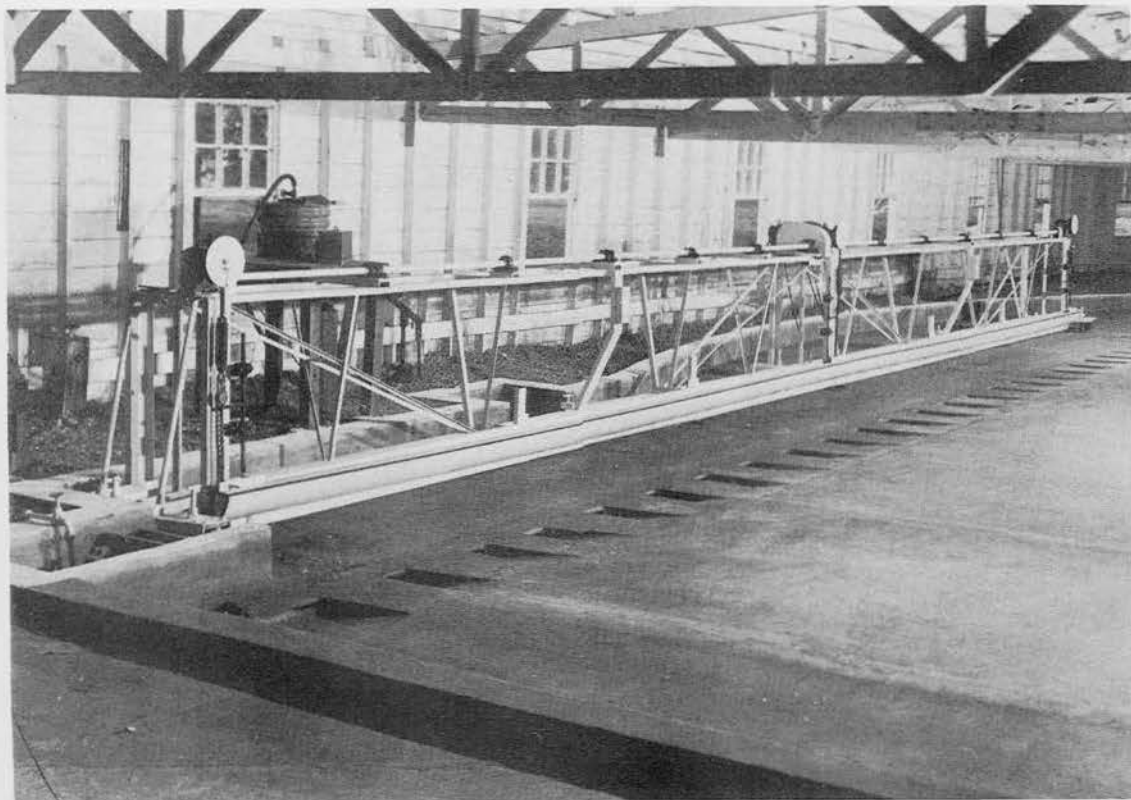


Fig. 3. Wave machine

Wave-height measuring device

12. Wave heights in the model were measured with a device designed and constructed at the Experiment Station especially for this purpose. This wave-height measuring gage (figure 4) consisted of a resistance staff installed in a direct-current circuit in which the individual resistors were so arranged that the current through the circuits

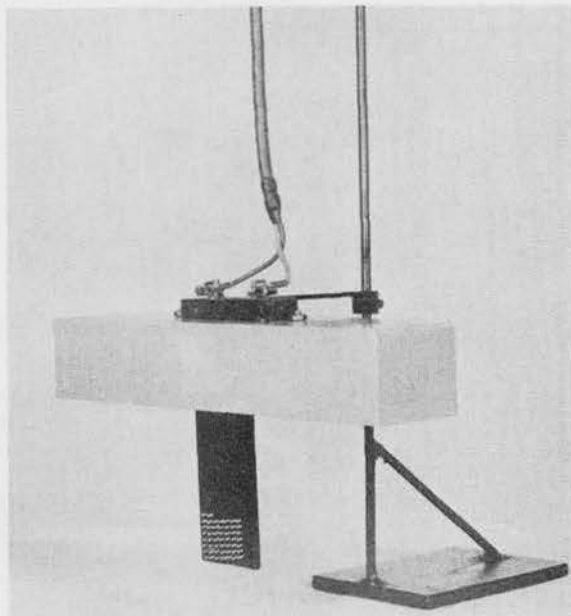


Fig. 4
Wave-height measuring device

varied directly with the submergence of the staff in water. The gages were calibrated by varying the submergence of the staffs in still water and observing the corresponding current drain on a milliammeter. The external contacts of each gage were exposed along the face of the staff in 0.002-ft vertical increments (model). The gages, therefore, were capable of detecting vertical fluctuations of the water surface with an accuracy of 0.002 ft in the model, corresponding in this case to 0.4 ft prototype.

Wave-height recording apparatus

13. In order to record for measurement the rapid fluctuations of current in the gage staff circuit (which fluctuations correspond to wave heights in the model), the electrical leads from the gage staff were connected to a modified D'Arsonval galvanometer of a recording oscillograph

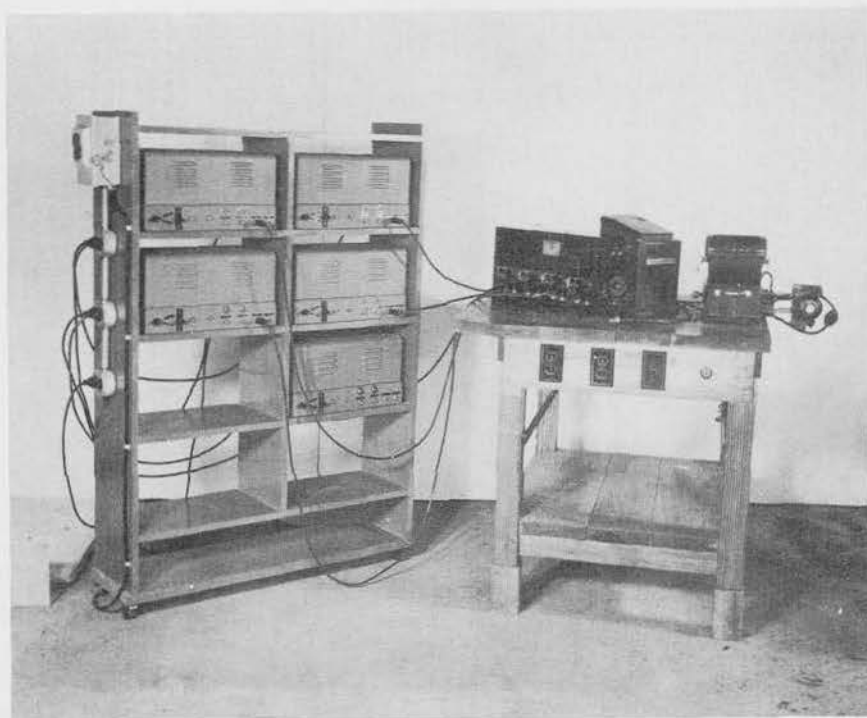


Fig. 5. Wave-height recording apparatus

(figure 5). The oscillograph contained seven of these modified D'Arsonval (moving coil) galvanometer units, each unit being so installed that its deflections, resulting from electrical current changes in the gage staff circuit, were transmitted as a beam of light to a strip of moving, sensitized, photographic recording paper. The resulting record or oscillogram was a two-dimensional graphic plot of model waves to a known scale, from which it was possible to measure wave heights.

Circulating system

14. Prototype ebb-tide currents were reproduced in the model by means of a circulating system consisting of three interconnected headers located in such manner that water was introduced into the southeast portion of the turning-basin area and withdrawn from the area west of the landing field (figure 6). The headers were equipped with adjustable ports

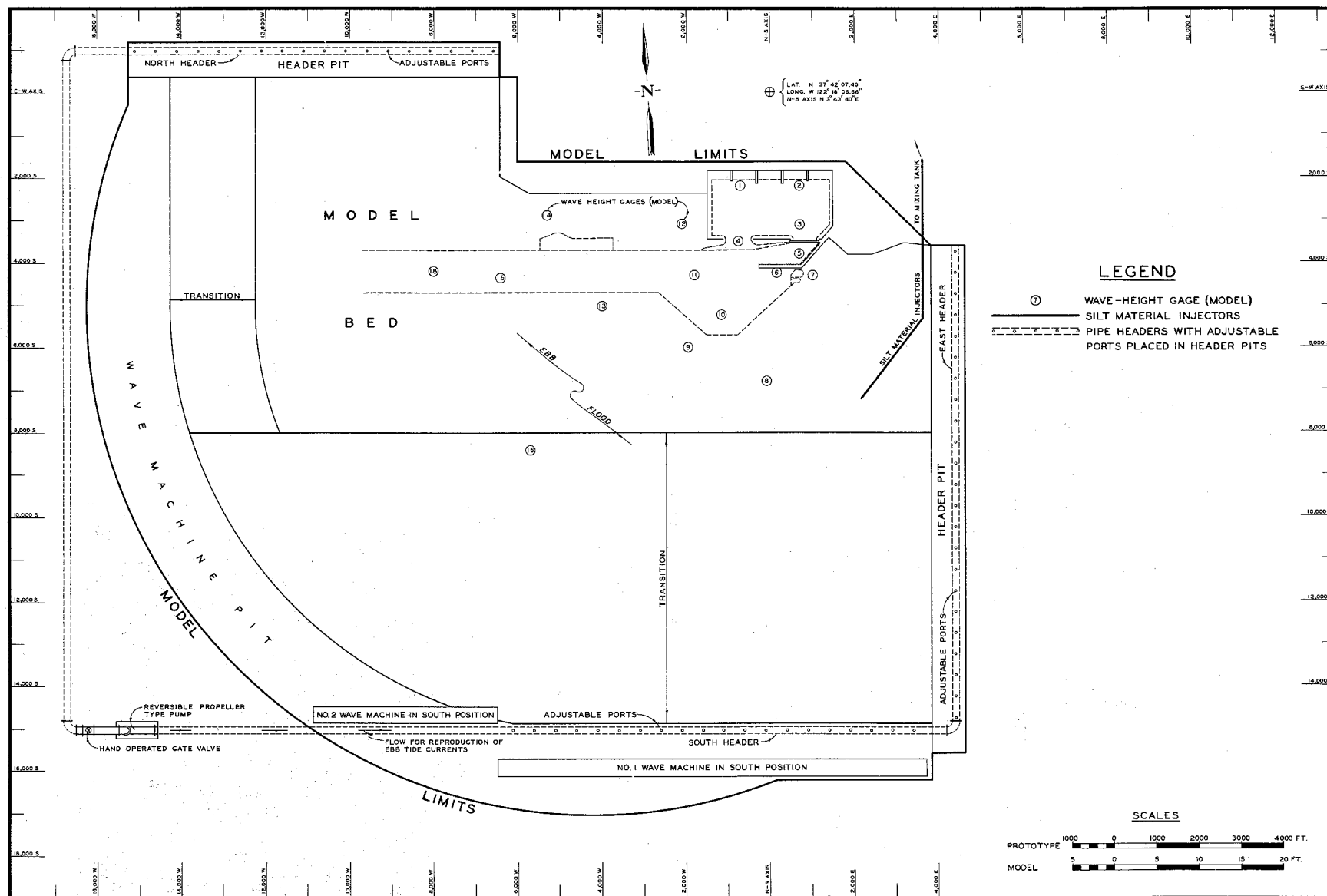


Fig. 6. Model layout

by means of which the quantity of water discharged from each port could be controlled. A motor-driven, propeller-type pump was placed in the pipe line connecting the headers, and the quantity of water circulated was measured by an orifice plate in the line. The magnitude and direction of the ebb-tide currents were controlled by manipulation of the adjustable ports in the headers and by regulation of the quantity of water circulated. A system of guide vanes placed outside the problem area insured a more accurate control of the tidal currents.

Shoaling material and apparatus

15. For the shoaling tests a light-weight material which would approximate the action of material in suspension in the prototype was required. The material selected was gilsonite, a natural asphaltic-like compound with a specific gravity of about 1.03-1.05. To prepare it for model use, the gilsonite was ground to a medium grain size of about 0.15 mm and then thoroughly mixed with water. Prototype shoaling action was simulated by placing a properly-proportioned mixture of gilsonite and water in a mixing tank and introducing this mixture into the model in the area from which the prototype silt material originated.

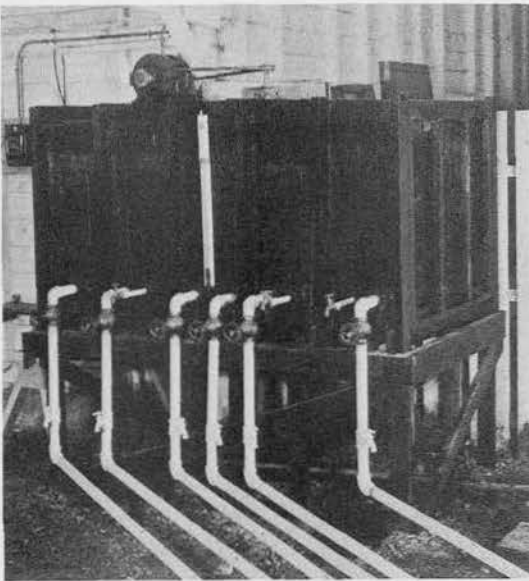


Fig. 7. Mixing tank

16. The shoaling apparatus consisted of a mixing tank and silt material injectors. The mixing tank was

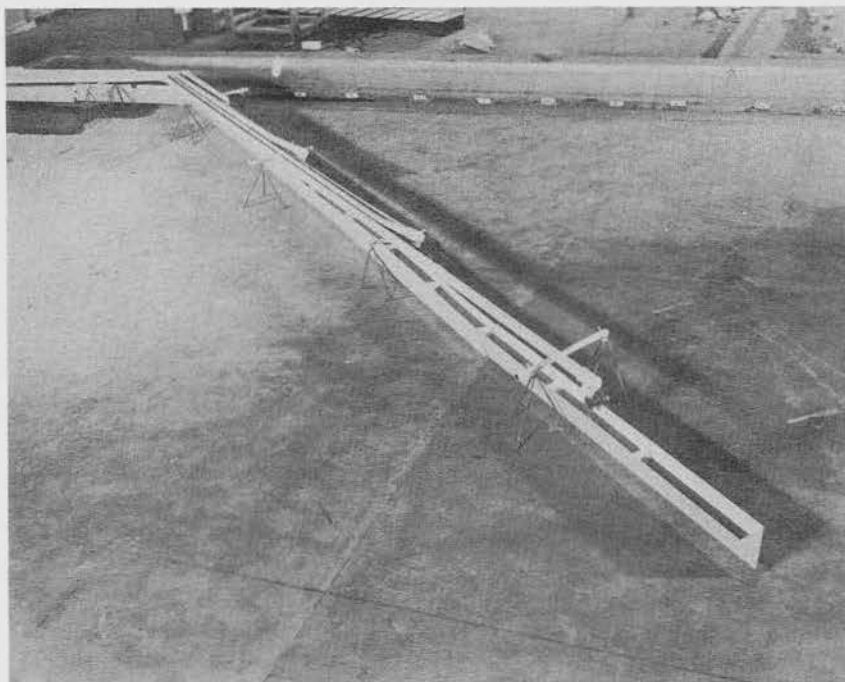


Fig. 8. Silt material injectors and header pit

equipped with a motor-driven propeller for agitating the water-gilsonite mixture during the model tests. Attached to this tank was a system of valves and pipes for distribution of the water-gilsonite mixture to the injectors. Troughs with triangular-shaped end sections and 1/8-in.-diameter holes spaced along the trough bottom assured an even distribution of the mixture into the model (see figures 6, 7, and 8).

Test Program

17. In order to make a comprehensive investigation of the various plans of improvement, it was necessary that two types of model tests be conducted: wave height tests to determine the most satisfactory location, alignment and height of breakwater for protection from storm waves; and shoaling tests to determine the most efficacious location and alignment

of the proposed breakwater for eliminating or reducing the amount of shoaling in the dredged turning basin. The investigation of plans for elimination or reduction of shoaling consisted of two series of model tests: (a) current studies to determine the effectiveness of the various plans of improvement in deflecting ebb-tide currents away from the navigation opening in the breakwaters; (b) qualitative shoaling tests of plans selected on the basis of the current-study tests to determine their effectiveness in reducing the amount of shoaling.

18. During a conference held 19-21 April 1943 at the Experiment Station between representatives of the Bureau of Yards and Docks and the Experiment Station, it was decided that the complete testing program should consist of four series of tests to be conducted in the following sequence: (a) tests to determine the best plan for protecting the problem area from storm waves; (b) tests to determine the best plan for elimination or reduction of shoaling in the dredged turning basin; (c) tests to determine the best plan for protection against both wave action and silting; and (d) investigation of the finally-selected plan, which plan would be selected from the series-(c) tests and modified as necessary to satisfy aircraft operational requirements. During the course of the model study it was decided to incorporate into the testing program tests to determine the optimum height of the breakwater.

19. Table 1 presents a comparison of the lengths of proposed breakwaters and plates 1-11 show the elements of the plans tested.

PART III: WAVE HEIGHT TESTS

Selection of Test Conditions

20. Before conducting tests to determine the effectiveness of various plans for protecting the problem area from storm waves, it was necessary that certain basic prototype conditions be established in order to reproduce on the model the storm wave action of the prototype. From a study of information available it appeared that the storms which frequent this area of San Francisco Bay usually approach from the southeast to southwest directions. However, since the fetch of San Francisco Bay southeastward from the problem area is small, this area was not reproduced on the model. Waves approximately 10 ft in height and about 200 ft in length were said to have been observed to approach the carrier pier at an angle of about 35 degrees west of south. The maximum water-surface elevation recorded during severe storms was about +9.6 ft mllw. Therefore, the wave action tests were conducted with the water surface maintained at +9.6 ft mllw and a wave of sufficient size was generated in the bay to result in a wave nearly 10 ft in height in the vicinity of the carrier pier. Waves were reproduced in the model from the directions of south, south 20 degrees west, and southwest.

Testing Procedure

21. For each proposed plan of improvement, waves were generated outside the problem area from the south, south-20-degrees-west, and southwest directions, and for each of these conditions the resulting wave heights at various points in the model were recorded (except for tests of

certain plans which were so similar to others that the recording of data from the south-20-degrees-west direction was not thought necessary). A comparison of wave heights for each plan of improvement with wave heights of the appropriate base test determines the relative effectiveness of the plan in protecting the problem area from storm wave action. Also, comparison of wave heights of similar or dissimilar plans of improvement provides an evaluation of the effects of different elements of the plans tested. In evaluating results of tests of the various plans, more weight should be given to wave heights recorded on model gages 1-7, which are located in the lagoon and adjacent to the carrier pier (figure 6).

Tests and Results

Base tests

22. The purpose of base tests is to obtain data which will serve as a basis of comparison, and by which the relative effects of different plans tested can be determined. With existing prototype conditions installed in the model, waves approximating those of the prototype were generated outside the problem area and resulting wave heights were recorded at critical locations in the problem area. Prototype conditions and the locations of model wave-height gages are shown on figure 6.

Plan 1

23. Description. This plan consisted of a breakwater located approximately parallel to the east line of the turning basin, extending from the shore line 3150 ft into the bay with a leg 900 ft long aligned east and west (see plate 1). This structure was a rubble-mound breakwater

with a crown width of 6 ft at elevation +12 ft mllw, and with side slopes of 1 on 1-1/4.

24. Results. In general, results of the tests indicated that plan 1 was not very effective in reducing wave heights in the problem area. Slight improvements were made in the vicinity of the carrier pier for waves from the south direction, but for waves generated from the south-20-degrees-west and southwest directions no improvement was noted. The failure of this plan to have the desired effect was attributed to the insufficient length of the westerly arm of the breakwater and to its top elevation, which permitted some overtopping of waves. Plate 12 shows wave height results of plan 1 compared with the base test.

Plans 2, 2A, 2B, and 2C

25. Description. The alignment and height of the breakwaters of plans 2, 2A, 2B, and 2C were identical (see plate 1). These breakwaters inclosed the area of the turning basin on the east and south, and extended to a point about 250 ft south of the southern limits of the entrance channel and 1500 ft west of the junction of the entrance channel and turning basin. The breakwater structure was of the same cross section and top elevation as that of plan 1. The navigation openings in plans 2, 2A, and 2B were, respectively, 1000, 750, and 500 ft in width and were located south of and **in** line with the entrance to the lagoon. The purpose of the navigation opening was to provide a direct taxi route for seaplanes from the bay to the seaplane lagoon. In plan 2C the navigation opening was eliminated to determine whether the wave action behind the breakwater was the result of waves overtopping the breakwater, or of

waves entering the problem area through the navigation opening.

26. Results. Test results of the plan-2 series showed some reduction of wave heights in the vicinity of the carrier pier and in the south part of the turning basin, especially for waves from the southwest direction. Conditions in the lagoon were also improved slightly. From observations made on the model it appeared that waves overtopping the breakwater created considerable disturbance in the problem area. When storm waves approached from the south-20-degrees-west and southwest directions, it was observed that the waves would bend and travel down the entrance channel, fanning out over the area of the turning basin and lagoon. Some overtopping of the west lagoon jetty was noted. Comparison of the results of tests of plans 2, 2A, and 2B with those of the base test (plates 13-15) showed that, by restricting the width of the opening in the breakwaters, the wave action in the turning basin adjacent to the opening was reduced. The change in width of the navigation opening had little effect, however, upon wave action between the piers and in the lagoon. Elimination of the navigation opening, plan 2C, provided very little additional protection to the carrier pier and turning basin (plate 16). Analysis of results of these tests indicated that, as in the case of the plan-1 breakwater, the top elevation of +12 ft mllw was too low to provide much protection from large storm waves or to permit an accurate determination of the effects of width of navigation opening, breakwater alignment, etc. Since all wave height tests were conducted with a water-surface elevation of +9.6 ft, there was only 2.4 ft of freeboard above still-water level, and some overtopping, especially of the bay arm of the breakwater, by waves 10 ft in height was to be expected. However, the effects of

overtopping waves in the critical areas could not be evaluated prior to the tests of plans 1 and 2.

Plan 3

27. The plan-3 breakwater as originally set up in the testing program was the same as the plan-4 breakwater (described in the following paragraph), except that the top elevation of the plan-3 breakwater was +12 ft mllw. Tests of plan 3 were omitted because the tests of plans 1 and 2 had indicated that a breakwater height of +12 ft would not adequately protect the problem area with model test conditions representing maximum conditions of waves and high water known to have occurred in the prototype.

Plans 4, 4A, 4B, and 4C

28. Description. As shown on plate 2, each plan of this series was identical with respect to alignment and height of the breakwater. In plans 4, 4A, and 4B the widths of the navigation openings were 1000, 750, and 500 ft, respectively. In plan 4C the navigation opening was eliminated. The breakwaters in this series inclosed a triangular-shaped area between the east line of the turning basin and the east shore line, and the area of the turning basin to a point about 1600 ft west of the junction of the south line of the entrance channel and turning basin. The protection of the triangular-shaped area to the east of the turning basin was included in this plan because proposed future plans for the Alameda Naval Air Station project included the possible construction of another lagoon in this area. The breakwaters were constructed in the model with a crown width of 6 ft at elevation +17 ft mllw; side slopes were 1 on

1-1/4. The top elevation of the breakwater was raised from the elevation of +12 ft mllw to an elevation of +17 ft mllw in order to reduce overtopping. This was necessary, as explained previously, to furnish additional protection to the problem area and permit determination of the effects of varying the widths of the navigation openings and other slight changes in improvement plans.

29. Results. Test results of the plan-4 series showed some protection from storm wave action in the vicinity of the carrier pier and at the entrance to the lagoon. The top elevation of +17 ft mllw eliminated overtopping of the breakwaters, yet there was still evidence of waves entering the problem area from the entrance channel. A reduction in the width of the navigation opening from 1000 to 750 ft resulted in a small reduction of wave heights in the vicinity of the piers and in the south part of the turning basin. Further reduction in the width of the navigation opening to 500 ft provided only slight additional protection. Plates 17-20 show wave height results of these plans compared with those of the base test. Elimination of the navigation opening (plan 4C) resulted in considerable reduction of wave action in the vicinity of the piers and in the turning basin when the direction of wave approach was from the south. However, practically no improvement was noted over that of plans 4, 4A, or 4B with storm waves approaching from the southwest direction. In general, results of the plan-4 series indicated that the alignment and top elevation of the breakwaters were satisfactory, but it appeared that additional protection could be gained by extending the breakwaters westward and parallel to the entrance channel.

Plans 5, 5A, 5B, and 5C

30. Description. Elements of plans 5, 5A, 5B, and 5C are shown on plates 2 and 3. The breakwater alignment of the plan-5 series was the same as that of the plan-2 series. The top elevation of the plan-5 series breakwater, however, was placed at +17 ft mllw, instead of +12 ft mllw, to eliminate overtopping. The elements of the plan-4 and plan-5 series differed in that, for the plan-4 series the shoreward arm of the breakwater included the triangular-shaped area to the east of the turning basin, whereas the plan-5 series did not. The navigation openings in plans 5, 5A, and 5B were, respectively, 1000, 750, and 500 ft in width, and were located south of and in line with the entrance to the lagoon. In plan 5C the navigation opening was eliminated to study the effect of waves that entered the problem area by bending and traveling along the entrance channel into the problem area.

31. Results. Test results of the plan-5 series showed a reduction in wave heights in the western part of the lagoon, in the pier area, and in the turning basin. The amount of reduction was about the same as that provided by the plan-4 series. A comparison of the test results of plans 5 and 2 shows that plan 5 was more effective in reducing wave heights for all wave directions tested. This is attributed to the increase in top elevation of the breakwater. As in previous tests the reduction in width of the navigation opening from 1000 to 750 ft, or to 500 ft, reduced wave action very little in the problem area. A comparison of the effects of varying the width of the navigation opening is shown by the data on plates 21-24. Elimination of the navigation opening indicated that, with storm waves approaching from the south and south-20-degrees-west

directions, wave action in the problem area would be reduced to such a degree that a safe anchorage should result. However, with waves approaching from the southwest, plan 5C provided little better protection than the other modifications of plan 5.

Plans 6, 7, and 8

32. Description. Plans 6, 7, and 8 (plates 3 and 4) were the same as plan 4A except that extensions of varying lengths parallel to the entrance channel were added to the west end of the plan-4A breakwater. The center line of the navigation opening and the top elevation of the breakwater (+17 ft mllw) were unchanged. From results of previous tests the 750-ft navigation opening appeared to be as efficient in reducing wave action in the problem area as the 500-ft width opening, and 750 ft was considered to be the smallest opening which would not interfere with aircraft operational requirements. Therefore, it was decided to test all additional plans of improvement with a navigation opening 750 ft in width. The breakwater extensions to the west end of plan 4A amounted to 2000, 4000, and 6000 ft, respectively, for plans 6, 7, and 8. These extensions were added to determine the minimum length of breakwater extending westward parallel to the entrance channel that would give maximum protection to the problem area, especially for waves approaching from the southwest direction.

33. Results. The addition of 2000 ft to the plan-4A breakwater (plan 6) reduced wave action in the lagoon and pier areas only slightly over that observed during the tests of plan 4A. Plate 25 shows wave heights recorded for plan 6 compared with those of the base test. The

addition of 4000 and 6000 ft of breakwater (plans 7 and 8) also improved wave conditions in the lagoon and at the carrier pier, but the amount of improvement over that observed with plan 6 installed in the model was so slight that it is doubtful whether the extra length of breakwater required to obtain this reduction could be justified economically; hence, for all practical purposes plans 6, 7, and 8 provided about the same degree of protection from storm waves. The installation of the breakwater along the channel did not appear to create any conditions that would be hazardous to navigation in the channel and did serve to protect the landing field from the damaging effects of storm waves. Plates 26 and 27 show the wave heights of plans 7 and 8 compared with those of the base test.

Plan 9

34. Description. The elements of plan 9 (plate 4) include all the elements of plan 6 with an additional breakwater extending south from the southwest corner of the landing field seawall to within about 150 ft of the north side of the entrance channel. The center line of the navigation opening and the top elevation of the breakwater were unchanged. This plan was tested because it was believed possible to reduce waves entering the channel by restricting the opening between the landing field shore line and the breakwater paralleling the channel.

35. Results. Results of the tests of this plan indicated that plan 9 would provide as much reduction in wave heights in the lagoon and between the piers as was accomplished by plans 6, 7, or 8. The spur dike projecting from the landing field was shorter than the extra 2000 ft of

breakwater in plan 7 or the extra 4000 ft of plan 8, and, therefore, would be more economical. The degree of protection provided by plan 9 was slightly greater than that provided by plan 6, but it is not believed great enough to justify the extra cost of the spur breakwater. Plate 28 shows wave height results of plan 9 compared with those of the base test.

Plans 10, 11, and 12

36. Description. Plans 10, 11, and 12 (plate 4) were devised to study the effect of alignment of the breakwater west of the navigation opening. The plan-10 breakwater was aligned by projecting a line from the western terminus of plan 7 to the west end of the east-west line of the plan-4A breakwater. The plan-11 breakwater was similar to plan 10 except that the western terminus was about 500 ft south of the west end of the plan-10 breakwater. In plan 12 the west or bay arm of the breakwater was revolved in such a manner that it was south of, and parallel to, the entrance channel. In all three plans the center line and width of the navigation opening and the top elevation of the breakwater were unchanged.

37. Results. Comparison of wave heights at the critical gages (1-7) for plans 10, 11, and 12 showed that about the same wave protection was obtained as that provided by plans 6 and 7. Plan 12 showed slightly higher waves at a few gages, indicating that moving the breakwater southward from the entrance channel permitted more wave energy to enter and pass up the entrance channel. Plates 29-31 present a comparison of the results of these plans with those of the base test.

Plan 13

38. Description. The elements of plan 13 (plate 5) were the same as plan 7 except that the shoreward arm of the plan-13 breakwater was revolved in such a manner that the breakwater was aligned similar to the shoreward arm of the plan-1 breakwater. The center line of the navigation opening and the top elevation of the breakwater were unchanged.

39. Results. To expedite the testing program on the wave action phase of the model study the test of plan 13 with storm waves from the south-20-degrees-west direction was omitted. With plan 13 installed in the model the magnitude of the waves in the problem area was about the same as that which obtained for the plan-7 tests. This indicates that a selection between plans 7 and 13 would depend upon whether protection is desired for the area east of the turning basin, which area had been designated for future expansion. Plate 32 shows wave height results of plan 13 compared with those of the base test.

Plan 14

40. Description. Plan 14 (plate 5) was the same as plan 13 except that the 750-ft navigation opening was placed in the shoreward arm of the structure to study the effects of reducing the effective width of opening on the entrance of storm waves.

41. Results. Placing the navigation opening in the shoreward arm of the breakwater reduced the disturbances in the problem area created by storm waves from the south and southwest directions. This system of breakwaters appears to be as satisfactory in reduction of wave action in the problem area as any of the other plans investigated. However, to

achieve such reduction of wave action it would be necessary to sacrifice some aircraft operational advantages afforded by a navigation opening located directly south of the entrance to the lagoon. Consideration of the shoaling problem also indicates the undesirability of this plan. Plate 33 shows wave height results of plan 14 compared with those of the base test.

Plan 15

42. Description. Plan 15 (plate 5) consisted of a breakwater surrounding the problem area except for a 750-ft seaplane navigation opening south of and in line with the lagoon opening, and the navigation opening for the entrance channel. The breakwater structure extending from the landing field seawall to the entrance channel was designed to reduce the opening through which waves could pass into the problem area. The plan-15 breakwater was similar to plan 4A except for the addition of the north-south spur projecting from the landing field seawall; also it did not provide protection for the area east of the turning basin as did plan 4A.

43. Results. Test results of plan 15 showed a satisfactory reduction of wave action in the problem area. With storm waves approaching from the south the results of plan 15 were about the same as those of plans 4A, 7, and 9. With waves approaching from the southwest, plans 7 and 9 were slightly more effective in the critical area of the piers; however, plan 15 requires about 5570 and 5120 ft, respectively, less breakwater than plans 7 and 9. Plate 34 shows wave height results of plan 15 compared with those of the base test.

Discussion of Results

Effect of breakwater height

44. Comparison of the results of plans 2C and 5C permits determination of the effects of breakwater heights. The elements of the two plans were the same except that the top elevation of the plan-2C breakwater was +12 ft mllw, whereas in plan 5C it was +17 ft mllw. This higher elevation practically eliminated overtopping, which in turn reduced wave action in the problem area. Elimination of overtopping made possible an accurate evaluation of the advantages and disadvantages of the various elements of similar and dissimilar plans. The top elevation of +17 ft mllw for the model breakwater was arbitrarily selected as a model expedient to reduce excessive overtopping of the model breakwaters. Since it was thought that a prototype breakwater with a +17-ft top elevation would not be necessary to protect the problem area from storms most likely to occur, it was decided to incorporate into the testing program a series of tests to determine the optimum height breakwater. These tests are described in Part V of this memorandum.

Effect of width of navigation opening

45. The results of tests of plans 4, 4A, 4B, and 4C, which were the same except for the navigation-opening width, illustrate the effects of various widths of navigation openings. A study of the data obtained for these plans indicates that, from a practical standpoint, a 750-ft opening is preferable. The slight advantage of plan 4B as compared with plan 4A would probably not justify the possible hazards that a 500-ft navigation opening might present in the operation of seaplanes. With the

navigation opening completely closed the reduction of wave heights was considerable, especially for waves from the south and south-20-degrees-west directions. However, this plan of improvement appears to present difficulties to taxiing aircraft that would outweigh its advantages with relation to protection against storm waves. Weighing carefully all of the factors involved, the 750-ft navigation opening is thought to provide optimum protection from storm wave action and at the same time more nearly satisfy operational requirements.

Effect of location of navigation opening

46. The results of plans 13 and 14 (identical except for the location of the navigation opening) present a comparison of effects of different locations of the navigation opening. With the navigation opening located south of and in line with the opening into the lagoon, storm waves which approach from the southeast to southwest directions travel through the opening and expand radially over the problem area. Locating the navigation opening in the shoreward arm of the breakwater permits only those storm waves from the southeast to enter the problem area through the navigation opening without bending. With waves approaching from the south the effective width of the opening for entrance of a wave front would be reduced from 750 to 500 ft, and with waves approaching from the south-20-degrees-west and southwest directions, the transverse axis of the navigation opening would be approximately normal to the wave fronts. These conditions would reduce considerably the wave energy entering the problem area through the seaplane navigation opening. Locating the navigation opening in the shoreward arm of the breakwater reduced to a satisfactory extent the storm wave action in the problem area, but

there is the possibility that this plan would interfere with the operation of seaplanes; also, shoaling might be accelerated.

Effect of increasing breakwater length parallel to entrance channel

47. Comparison of the results of plan 4A with those of plans 6, 7, and 8 was made to determine the minimum length of breakwater extending westward along the entrance channel which would provide sufficient protection from storm waves. Plans 6, 7, and 8 were formed by adding successive 2000-ft increments to the west end of the plan-4A breakwater. From a study of the data obtained from tests of these plans it was found that the addition of 2000 ft, 4000 ft, and 6000 ft to the west end of the plan-4A breakwater provided successively greater, but only slightly better, protection than did plan 4A. The slight increase in protection does not appear to justify the additional length of breakwater involved; therefore, plan 4A is considered the most practical system of protective works of this particular alignment.

Effect of breakwater alignment (bay arm)

48. From the results of plans 7, 10, 11, and 12 (which were similar except for variations in the alignment of the west or bay arm of the breakwaters) it was concluded that aligning the bay arm of the breakwaters in such manner as to increase the width of opening between the landing field seawall and the west end of the breakwater would result in a decrease in the effectiveness of the protective works. This decrease in effectiveness is due to the wider wave front traveling up the entrance channel into the problem area. The only advantage obtained is the slight decrease in breakwater length permitted by this type alignment.

49. Plans 7 and 13 were also similar except that the alignment of the shoreward arm of the plan-13 breakwater did not include the area east of the carrier pier proposed for future development. Comparison of results of these two plans revealed that, in the critical areas (gages 1-7), the differences in wave heights were negligible. Therefore, it was concluded that the alignment of the shoreward arm of the breakwater would be of no significance from the standpoint of storm wave protection. The only advantage of plan 7 over plan 13 is that an additional area is protected from storm wave action.

Effect of restricting the opening between the
landing field seawall and entrance channel

50. Plans 9 and 6, used to study this aspect of the problem, were similar except that plan 9 had the added feature of a spur breakwater which extended south from the southwest corner of the landing field seawall to within approximately 150 ft of the entrance channel. Wave heights were reduced slightly in the problem area, when waves approached from the south-20-degrees-west and southwest directions, by the addition of this spur breakwater to plan 6. With waves approaching from the south direction the spur breakwater had little effect upon the magnitude of wave heights in the problem area. The degree of protection afforded by plan 9, when compared with plan 6, does not appear to justify the additional cost of the spur breakwater.

51. Comparison of results of plans 4A and 15 shows the effect of adding the spur breakwater. Although the shoreward ends of the breakwaters in plans 4A and 15 were different, tests of plans 7 and 13 showed that alignment of the shoreward arm had no appreciable effect on wave

action in the critical areas. With storm waves approaching from the south direction the addition of the spur breakwater would reduce wave heights in the vicinity of the piers, and with waves approaching from the southwest the disturbance in the lagoon and the turning basin would be reduced, while in the vicinity of the piers conditions would remain practically unchanged.

52. The elements of plans 9 and 15 were also similar to the extent that both plans inclosed the problem area except for the navigation openings. However, plan 9 inclosed an area considerably larger than that inclosed by plan 15 and would require a much greater length of breakwater. Comparison of results of these two similar plans indicates that with waves approaching from the south direction plan 15 would be more efficacious, but with waves approaching from the southwest direction plan 9 would be the better plan, especially for wave reduction in the vicinity of the piers. It is doubtful, however, whether the slight additional protection provided by plan 9 as compared with that of plan 15 is sufficient to justify the extra 5120 ft of breakwater required in plan 9.

Summary of results

53. From a study of results of the wave height tests it appears that plans 4-15 would provide about the same general protection to harbor facilities from storm wave action. These plans, excepting plan 14, appear to satisfy seaplane operational requirements. The location of the navigation opening in the shoreward end of the plan-14 breakwater would probably present some difficulties to taxiing aircraft and might prevent a satisfactory solution of the silting problem. The plan-4 and plan-5

series would provide good protection at the entrance to the lagoon and at the carrier pier, although other plans involving additional breakwater length to the west along the entrance channel (plans 6-14) would provide some slight additional protection from waves from the southwest directions. The alignment of the plan-5 breakwater is not believed to be of any practical value inasmuch as this breakwater encloses an area to the southeast of the turning basin which would not lend itself to improving existing harbor facilities or providing additional protected area for future installations. Plans 6, 7, and 8 would provide almost equal protection to the problem area from storm waves, but plans 7 and 8, as compared with plan 6, involve some 2000 ft and 4000 ft additional breakwater in deeper water; from an economic standpoint this would outweigh the little added protection provided by these plans. Plan 9 provides as much protection as plans 7 and 8, and only slightly greater protection than plan 6. The increase in protection over plan 6 is so slight, however, that the cost involved in constructing the spur from the landing field seawall is not believed warranted. In the event that it is not desired to provide protection from storm waves for the area east of the existing carrier pier, the length of the shoreward arm of the breakwater could be reduced by using the shoreward arm alignment of plans 13 and 15. This change in alignment of the shoreward arm of the breakwater would not materially affect the degree of protection provided for the problem area. Additional economy of construction could be gained without materially affecting the degree of wave protection by installation of plan 4A using the shoreward arm alignment of plan 15. If protection of the shore facilities from storm wave action is considered of prime importance, then

plan 14 might be selected for installation. However, it is believed that consideration of operational requirements and silting will vitiate the good performance of plan 14. Plan 15 provides protection to most of the shore facilities from storm wave action although part of the landing field seawall is left exposed; yet, as mentioned previously, the slight additional protection effected by plan 15 as compared with plan 4A does not appear to justify the addition of the north-south spur breakwater.

54. On the basis of the results of the wave height tests, plan 4A using the shoreward arm alignment of plan 15 was selected as the plan that would provide the best over-all protection from storm waves at least cost. This selection is made assuming that it is not considered desirable nor necessary to provide protection for the triangular-shaped area east of the present carrier pier. Table 1 presents lengths of the breakwaters involved for each proposed plan, and tables 2, 3, and 4 present results of wave height tests for the base test and plans 1-20.

PART IV: SHOALING TESTS

Prototype ShoalingWave action and tidal currents

55. In conducting tests to determine the effectiveness of various plans designed to eliminate or reduce shoaling in the dredged turning basin, it was necessary that certain basic prototype conditions be reproduced in the model in order to simulate the shoaling action of the prototype. It had been concluded that the silt material being deposited in the turning basin was transported in suspension by ebb-tide flow from the mud flats between about the -10 ft mllw contour and the shore line southeast of the Naval Air Station. Therefore, this area was selected as the injection point for the model silt material. Although prototype shoaling was a day-to-day phenomenon, data seemed to indicate that the rate of shoaling was accelerated by storm wave action. The maximum tide elevation during storm action had been observed to range from +8.5 to +9.6 ft mllw. It was decided to conduct the silt tests with a still-water elevation of +8.5 ft mllw and to reproduce the strength of ebb currents. Float studies conducted in the prototype (plate 46) provided data as to the magnitude of velocities and direction of currents at strength of ebb for use in the model study. Light to strong winds from the west and south prevail in this area throughout the year, creating a choppy water condition in the bay area. To create a condition in the model which would agitate the model silt material in a similar fashion, it was found necessary to generate waves about 3 ft in height from the south direction.

Shoaling data

56. From periodic surveys beginning about December 1942 and continuing through December 1943, profiles were plotted along ranges in the problem area where the maximum amounts of shoaling occurred. From these profiles the location and depth of material deposited were determined; these data are presented on plates 48-52. During these periods shoaling in the westerly half of the turning basin was very light, and for this reason shoaling data in this area are not shown.

57. During the period from December 1942 to March 1943, which included the storm of 20-23 January 1943, the greatest amount of shoaling occurred in the area bounded by the tender pier, the causeway, and the carrier pier (plate 48). The area located immediately south of the carrier pier and extending west approximately 1800 ft also shoaled appreciably, while in the remainder of the turning basin the deposition was comparatively light. Plate 49 shows shoaling which occurred during the period from March to May 1943; although no storm occurred during these months a large amount of material was deposited in the area between the tender pier and carrier pier. On plate 50 it may be seen that the shoaling from May to August 1943 was comparatively light. Plate 51 shows depth and location of material deposited in the turning basin during the period August to December 1943; the storm of 8-9 December occurred during this period. It is seen that, although a storm occurred during these months, shoaling was comparatively light and fairly well distributed over about the easterly half of the turning basin. The shoaling during the August-December 1943 period was slightly greater than that which occurred from May to August, no storm having occurred during the latter period. Plate 52

delineates depth and location of material deposited in the turning basin during the period December 1942 to December 1943, when shoaling between the piers was extremely heavy. The area immediately south of the carrier pier and extending west approximately 1800 ft was also shoaled considerably, while in the remainder of the turning basin shoaling was fairly light.

Model Adjustment

Hydraulic adjustment

58. Existing conditions. Model silt-test conditions having been established, the next step was hydraulic adjustment of the model; i.e., reproduction in the model of the direction and magnitude of prototype ebb-tide currents. As previously stated, the model was provided with a circulating system by means of which the water could be introduced into the southeast portion of the turning-basin area and withdrawn from the area west of the landing field. By manipulation of the adjustable ports in the headers of this circulating system, and by regulation of the quantity of water circulated, the magnitude of velocities and the direction of model ebb-tide currents were adjusted to conform to those of the prototype. This tidal-current adjustment was performed without the reproduction of wave action. Plate 46 shows results of the adjustment of the model ebb-tide currents. The magnitude of the velocities and directions of the tidal currents, once established, were readily repeated by circulating a known quantity of water. During adjustment and prior to each test the magnitude and direction of the ebb-tide currents were checked at various points on the model by use of surface floats.

59. Test conditions. Although the method of hydraulic adjustment described in the previous paragraph was satisfactory for existing prototype conditions, it was not believed that the change in direction of prototype ebb currents caused by installation of the proposed breakwater plans would be correctly reproduced in the model. Accordingly, it appeared reasonable to estimate the revised ebb-tide current pattern in the vicinity of the breakwaters and readjust the model to reproduce these estimated or assumed ebb-tide currents. Plate 47 shows these assumed currents and the model ebb currents adjusted to simulate them with a typical plan installed in the model. This current adjustment was also performed without wave action.

Shoaling adjustment

60. Following the hydraulic adjustment of the model to reproduce the direction and magnitude of prototype currents, the model was adjusted to reproduce prototype shoaling action. During preliminary adjustment tests it was determined that relatively large quantities of shoaling material would be deposited in the turning basin when existing prototype conditions were reproduced, whereas relatively minor quantities of shoaling material were deposited in the turning basin when any of the proposed breakwater plans was installed in the model. Since the difference in shoaling with and without improvement works installed was so large, it was concluded that it would not be necessary to attempt a close quantitative reproduction of the rate of prototype shoaling. Instead, it was concluded that relative effects of the various proposed breakwater plans could be determined qualitatively by establishing arbitrary quantities of

model silt material (gilsonite) to be injected in the area from which the shoaling material was assumed to originate, and to establish arbitrary time limits for tests during which time the injected silt material would be carried toward and deposited in the turning basin.

61. The adjustment of the model for this qualitative reproduction of prototype shoaling involved determination of the proper amount and points of injection of the model silting material. Preliminary shoaling tests made during this adjustment indicated that wave action was necessary in the bay area to help keep model silt material in suspension. It was found that a 3-ft wave generated from the south direction was satisfactory for this purpose. It was also noted that prototype ebb currents, when reproduced to the correct model scale, were not sufficient to move the silt material in the desired quantities. Accordingly, model currents were increased sufficiently to transport the silt material from the point of injection to the problem area.

62. The turning basin was divided into eight areas and the volume of model silt material deposited in each area was measured for comparison. The amount of shoaling obtained in these areas with an improvement plan in place, divided by the amount of shoaling obtained during the base test, represents a shoaling index. Shoaling indices greater than unity indicate an increase in the amount of shoaling over that obtained with the base test, and shoaling indices less than unity indicate a less amount of shoaling. These shoaling indices may also be used to calculate percentile reduction* in shoaling.

* $(1 - \frac{A_p}{A_b}) 100$ = per cent reduction of shoaling when the ratio $\frac{A_p}{A_b}$ = the shoaling index.

Development of Improvement PlansSelection of initial plan

63. From results of the wave height tests, plan 4A using the shoreward arm alignment of plan 15 had been selected as the most desirable plan for installation in the prototype. This selection was made at a time when it was not considered desirable or necessary to protect the triangular-shaped area east of the present carrier pier. However, this area was later designated for possible future developments, and additional docking facilities were proposed for construction in lieu of the previously proposed construction of an additional seaplane lagoon. Since it was considered desirable to inclose these additional docking facilities by any breakwater scheme proposed, a modification of the plan-4A breakwater to inclose these additional facilities was adopted for investigation in the shoaling tests. Since it had been determined that the exact location and alignment of the shore portions of the breakwater were of no significance from the standpoint of protection from waves, although it was necessary that the shoreward portions be constructed, a modification of the plan-4A breakwater (plan 16, see plate 5) was developed to inclose the additional docking facilities.

64. Following the preliminary silt tests of base test conditions and plan 16, it was thought desirable to modify plan 16 further, to reduce the over-all length of breakwater involved. Accordingly, plans 17 and 18 were developed. These plans were identical except for the widths of the seaplane navigation opening, 750 ft and 500 ft wide, respectively.

Current direction tests

65. After shoaling tests of plan 16 had been completed a series of current-study tests was conducted on thirteen modifications of plan 17 and six modifications of plan 18. Two additional plans (plans 19 and 20) were also devised and tested in this series. The elements of these plans are shown on plates 5-10. These tests were performed to determine the characteristics of each plan in deflecting ebb-tide currents away from the turning basin. From results of these tests, those plans which allowed the least current through the seaplane navigation opening into the turning basin were chosen for further study in the comprehensive shoaling tests.

Tests and Results

Base tests

66. A preliminary shoaling base test was made using model currents which reproduced to scale the prototype ebb-tide currents, and with the shoaling material introduced into the model as previously described. Results of this test are shown on plate 53. It was noted from the base-test results that prototype ebb currents, when reproduced to model scale, were not of sufficient strength to move the model silt material in quantities comparable to prototype movement. Therefore, another base test was made using 3-ft waves to help keep model silt material in suspension, and model currents were increased sufficiently to transport the silt material from points of injection to the problem area. To insure that the model was capable of repeating itself, with respect to position and quantity of shoaling, a check run was performed for this base test. The results of

these tests are shown on plates 61 and 62. All base tests conducted were performed to provide a basis for evaluating the effects of the various improvement plans. The test results of plan 16 were the only improvement-plan shoaling data which were compared with the preliminary base test. Results of all other plans were compared with the later base tests.

67. The results of the model base tests and the prototype shoaling survey for the period December 1942 to December 1943 show that the greatest deposition of material occurred between the tender and carrier pier immediately to the west of the causeway and in the area immediately south of the carrier pier for both the prototype and the model base-test conditions. Shoaling in the entrance channel was comparatively light for the prototype, and also for the model base tests.

Plan 16

68. Description. Plan 16 (plate 5) consisted of a modification of plan 4A, wherein the bay arm of plan 4A was retained and the shoreward arm revolved clockwise to connect its eastern extremity with the north-south jetty which is incorporated in the proposed construction of additional docking facilities. A 300-ft north-south spur was installed on the east side of the navigation opening in the breakwater. A 750-ft navigation opening for sea-type aircraft was provided south of and in line with the navigation opening into the lagoon.

69. Results. The results of the silt test of plan 16 are shown on plate 54. These results should be compared with those of the preliminary base test which are shown on plate 53. Plan 16 effected satisfactory shoaling reduction but was not used for further testing since it was

thought desirable to modify the plan further in order to reduce the overall length of breakwater involved. Also, installation of plan 16 in the model caused a change in direction of prototype currents as simulated in the model, which change, it was believed, would not be duplicated by installation of this plan in the prototype. Therefore, as previously stated, it was decided to revise the ebb-tide current pattern in the vicinity of the breakwater and readjust the model to reproduce these assumed currents prior to conducting the remaining testing program on other plans.

Plans 17, 17A, and 17C

7C. Description. The elements of plan 17 and modifications thereof are shown on plates 5-8. This plan consisted of a further modification of breakwater plan 4A, to shorten the bay arm of the breakwater, with the shoreward arm remaining the same as that of plan 16. A 750-ft navigation or taxi opening for sea-type aircraft was provided south of and in line with the navigation opening into the lagoon. During current-direction tests of this plan, various combinations of north-south spurs of varying lengths were installed on both sides of the navigation opening to study the effectiveness of such structures in deflecting ebb-tide currents away from the turning basin. Since it did not appear practical to conduct silt tests on all of the plans investigated in the current-direction studies, only those plans were selected from the plan-17 current-study series which offered the greatest degree of protection for a minimum length of breakwater. Plan 17 was selected since north-south spurs at the navigation opening were not involved, and it was considered desirable

that this plan be included in the testing program to serve as a criterion for the evaluation of results of tests of plans involving north-south spurs. Installation of the 200-ft north-south spur on the east side of the navigation opening (plan 17E, plate 56) had little effect on ebb-tide currents entering the taxi opening. Results of current-study tests of plans 17F and 17G, which involved the installation of 100- and 200-ft north-south spurs, respectively, on the west side of the navigation opening in conjunction with the 200-ft spur on the east, showed that neither of these plans was very effective in deflecting ebb-tide currents away from the navigation opening. Results of tests of the plan-17 series with a 300-ft installation on the east side of the breakwater opening and with varying lengths of north-south spurs on the west side of the opening (plate 55) indicated that plans 17A and 17C offered optimum protection considering the lengths of breakwaters involved. Additional tests with 400- and 500-ft installations on the east side of the opening and various lengths of spurs added on the west side (plans 17H-17N, plates 56 and 57) indicated that the slight additional advantage of these installations would not justify the increased lengths of breakwaters involved. Therefore, since plans 17, 17A, and 17C appeared to be the best plans of this series (considering the lengths of breakwaters involved), they were selected for further testing to determine the most effective plan for the elimination or reduction of shoaling in the dredged turning basin.

71. Results. Results of shoaling tests of the plan-17 series indicated a large reduction of shoaling in the dredged turning basin, especially in the critical area of the piers. On the basis of the shoaling indices, plan 17 indicated a reduction in shoaling of about 90-95

per cent, which was the most satisfactory of this series in so far as the turning-basin area as a whole was concerned. However, tests of this plan showed a slight shoaling in the entrance channel, whereas, under existing conditions in the prototype, the shoaling in the entrance channel presented no problem. Results of tests of plan 17A and 17C show that these plans were slightly less effective than plan 17 in reduction of shoaling in the turning basin, however they allowed no appreciable deposits to occur in the entrance channel. Plans 17A and 17C showed an average reduction in the turning basin of 88 and 81 per cent respectively. For plan 17A, an eddy existed to the west of the 300-ft spur which carried a small amount of silt through the navigation opening in the direction of the carrier pier. Installation of the 200-ft spur to the west or bay arm of the breakwater at the navigation opening (plan 17C) destroyed this eddy, and the silt which entered the navigation opening was deposited in the western part of the turning basin. Plates 63-65 and table 6 show results of the silt test for the plan-17 series.

Plans 18, 18A, and 18B

72. Description. Elements of plan 18 (with modifications made for the silt investigation) are shown on plates 8 and 9. The plan-18 series was the same as the plan-17 series except that the navigation opening was reduced from 750 ft to 500 ft. The plan-18 series was devised to study the effects of width of navigation opening on shoaling in the problem area.

73. Results. A study of the results of current-direction tests of the plan-18 series (plates 58 and 59) shows that, as in the case of the plan-17 series, plans 18, 18A, and 18B were the most effective in

deflecting ebb-tide currents from the navigation opening, considering the lengths of breakwaters involved. Therefore, since these plans (18, 18A and 18B) were comparable to those selected from the plan-17 series, they were selected for testing with respect to shoaling. Results of the plan-18 series indicate an even larger reduction of shoaling in the turning basin, especially in the critical areas between the piers and south of the carrier pier. Plan 18 reduced shoaling in the turning basin to a very satisfactory degree, but, as in the case of plan 17, some shoaling occurred in the entrance channel. The average percentile reductions of shoaling in the turning basin effected by plans 18, 18A, and 18B were about 91, 95, and 98 per cent, respectively. Although results of tests of plan 18A appear favorable, the locations of the silt deposits behind the breakwater appear to be undesirable (in view of the proposed docking facilities) in that the material was deposited in the eastern portion of the turning basin and in the area adjacent thereto. Plan 18B appears to be the most desirable of the plan-18 series in that only very slight shoaling occurred in the turning basin north of the taxi opening. A light deposit was also noted between the shoreward arm of the breakwater and the turning basin. Plates 66-68 and table 6 show results of silt tests for the plan-18 series.

Plans 19 and 20

74. Description. The elements of plans 19 and 20 are shown on plate 10. Plan 19 was the same as plan 17A except that the bay arm of the breakwater was removed. Plan 20 was the same as plan 17 except that the bay arm was removed and an 800-ft east-west section was added to the shore

arm. These plans were devised and tested to study the effectiveness with respect to shoaling of improvement plans involving minimum lengths of breakwater. Little or no protection from storm wave action could be expected from these plans.

75. Results. Results of tests of plans 19 and 20 show a large reduction of shoaling in the turning basin area, especially in the critical area of the piers. The average percentile reductions of shoaling in the turning basin effected by plans 19 and 20 were about 84 and 88 per cent, respectively, indicating that plan 20 was slightly more effective than plan 19. Some material was deposited in the western part of the turning basin and at the junction of the turning basin and the entrance channel. The silt results of these plans are shown on plates 69 and 70 and table 6.

Discussion of Results

Interpretation of model results

76. The results of the model shoaling tests are considered reliable only in a qualitative sense. That is, the results are considered sufficiently accurate to show the relative effectiveness of the proposed plans. As mentioned previously, the rate of prototype shoaling was not simulated on the model, and, therefore, the model shoaling data are not quantitatively accurate.

Spur breakwaters at navigation opening

77. In general, the effects of spur breakwaters on shoaling in the problem area were found to be very good. The spurs deflected silt-bearing currents away from the navigation opening, which, in turn, reduced the

amount of silt transported into the problem area. Adding a spur on the east side of the navigation opening appreciably reduced shoaling in the entrance channel and turning basin. The addition of a spur on the west side of the navigation opening altered the location but did not reduce the amount of shoaling. The effects of spur breakwaters located at the 500-ft navigation opening were found to be about the same as for the 750-ft opening.

Width of navigation opening

78. When the seaplane navigation opening was reduced in width from 750 ft to 500 ft the currents through the opening were reduced about 8 per cent. This slight decrease in velocity, together with the decreased opening width, reduced appreciably silt deposition in the problem area. However, the general pattern and location of shoaling were not affected by the change in width of the navigation opening.

Eliminating bay arm of breakwater

79. Plans 19 and 20, which had the bay-arm portion of the breakwater removed, resulted in similar silt-deposition patterns, and both plans reduced appreciably the shoaling in the turning basin. However, considerable shoaling occurred in the entrance channel with these plans installed in the model. Therefore, a plan of this type should be considered for adoption only in the case where shoaling, and consequently periodic dredging of the entrance channel, could be tolerated.

PART V: TESTS OF PLANS SELECTED FOR FURTHER STUDY

Wave Height TestsSelection of plans

80. Four of the plans developed during the shoaling tests, described in Part IV, were investigated to determine their effectiveness in the reduction of storm wave action in the problem area. Those selected were plans 17C, 18B, 19, and 20. Plans 17C and 18B were selected to determine the effect of adding north-south spurs at the navigation opening, and plans 19 and 20 were selected to determine the effectiveness of plans which involved a minimum length of breakwater (no bay arm) on the reduction of wave heights in the problem area.

81. In a letter dated 9 August 1944, from the Commanding Officer, U. S. Naval Air Station, Alameda, California, to the Experiment Station, there was submitted a tentatively selected plan of improvement for installation in the prototype. This plan was designated plan 21 of the testing program and was a modification of plan 17C. Alterations to plan 17C to form plan 21 involved the following: (a) shifting the entire breakwater about 200 ft toward the south; (b) revolving clockwise the shoreward arm of the breakwater to an east-west alignment; (c) reducing the length of the shore arm and connecting its eastern extremity to a proposed east-west bulkhead; and (d) moving the seaplane navigation opening approximately 500 ft westward. In addition to the alterations of breakwater location and alignment, plan 21 proposed the following harbor improvements: (a) widening and lengthening the tender pier; (b) widening the existing carrier pier; (c) adding another carrier pier immediately south of the

existing carrier pier; (d) surrounding the area east of the existing carrier pier by a bulkhead and developing it for wharf frontage; and (e) enlarging the turning basin. As in the case of plan 17C, a 750-ft navigation opening was provided, and north-south spurs of 300 ft and 200 ft were used on the east and west sides, respectively, of the navigation opening. The bay arm of the breakwater was constructed in the model to a top elevation of +15 ft mllw, and the shoreward arm was constructed to an elevation of +12 ft mllw. These elevations were thought to be sufficient to provide adequate protection from overtopping waves for those storm conditions most likely to occur. Since the principal difference between the selected plan 21 and plan 17C was that of breakwater location, it was decided to test the selected plan using the same top elevation as that of plan 17C (+17 ft mllw for both arms of the breakwater) to determine the effect of the change in breakwater location on wave heights in the problem area. This plan was designated plan 22.

Plans 17C and 18B

82. The elements of these plans are shown on plates 6 and 9. Results of wave height tests of plan 17C showed considerable reduction of wave heights at the entrance to and in the seaplane lagoon, in the critical area of the piers, and in the west and south portions of the turning basin. However, as in the case of plan 4A, there was evidence of waves entering the problem area from the entrance channel. The reduction in width of the navigation opening from 750 ft to 500 ft (plan 18B) resulted in a further slight reduction of wave heights in the pier area and in the turning basin adjacent to the navigation opening. Plates 35 and 36 show

wave height results of plans 17C and 18B compared with those of the base test, and plate 37 shows the comparison of plans 17C and 18B. In general, results of the wave height tests of plans 17C and 18B were about the same as those of plans 4A and 4B. A comparison of results of tests of plans 4A and 17C and of plans 4B and 18B shows that addition of the north-south spurs at the navigation opening had little effect upon wave action in the problem area.

Plans 19 and 20

83. The elements of plans 19 and 20 are shown on plate 10. Results of wave height tests of these plans show that neither plan was very effective in reducing wave action in the problem area. For waves from the south direction, plan 20 effected some slight reduction of wave heights in the critical area of the carrier pier, but for waves from the south-20-degrees-west and southwest directions no great improvement was noted. Plates 38 and 39 show wave height results of plans 19 and 20 compared with those of the base test. As in the case of plan 1, the failure of these plans (especially plan 19) to provide the desired protection was attributed to the insufficient length of the westerly arm of the breakwaters. It is to be noted that the top elevation of plans 19 and 20 is +17 ft mllw, while that of plan 1 is +12 ft mllw, which probably accounts in part for the slightly better protection provided by plan 20.

Plans 21 and 22

84. The elements of plans 21 and 22 are shown on plate 11. When tested using maximum prototype conditions, plan 21 showed good reduction of wave heights in the lagoon (especially at the lagoon entrance), in the

critical area of the piers and in the turning basin. Compared with plan 17C, more overtopping of both arms of the breakwater was in evidence. Results of wave height tests of plan 21 indicated that the location, alignment and top elevations of the breakwater were satisfactory. Plate 40 shows wave height results of plan 21 compared with the base test. Plan 21 was also tested using wave heights and a still-water level which it was thought (paragraphs 95-98) would more nearly represent prototype conditions most likely to occur with sufficient frequency to justify protective measures. These conditions represented a still-water level of +7 ft mllw, and wave heights of about 7 ft in the problem area. Plate 42 shows results of these tests. Generally, wave heights in the vicinity of the carrier pier were reduced about 50 per cent or more by plan 21 for these latter base conditions.

85. Results of wave height tests of plan 22 (plate 41), using maximum prototype conditions, showed that the increase in breakwater elevation effected a slight reduction in wave heights in the problem area. A comparison of test results of plans 21 and 22 shows the effect of breakwater height, and comparison of results of plan 22 with those of plans 4A and 17C shows the effect of changing the breakwater location and alignment.

Discussion of results

86. Wave height tests of selected plans 17C, 18B, 19 and 20 showed that plans 17C and 18B would provide satisfactory protection from storm wave action, and that plans 19 and 20 were not very effective in reducing wave action in the problem area. The reduction of wave action afforded by plans 17C and 18B was comparable to that of plans 4A and 4B. This fact

strengthens the conclusion that the shoreward arm alignment of the breakwater is not critical with respect to wave action. The failure of plans 19 and 20 in protecting the harbor area from storm wave action is attributed to the insufficient length of breakwater (westerly arm) provided by these plans. Plans 21 and 22 would provide adequate wave protection to the harbor.

Shoaling Tests

Plans tested

87. In order to complete this phase of the testing program, shoaling tests were conducted on the Navy Department's tentatively selected plan, plan 21, and a modification thereof, plan 21A. Elements of these plans are shown on plate 11.

Results of tests -- plan 21

88. Plan 21 resulted in a large reduction of shoaling in the turning basin and in the critical area of the piers. Yet deposition of silt was fairly heavy adjacent to the navigation opening and slight shoaling was noted in the entrance channel. On the basis of shoaling indices, plan 21 was about 17 per cent less effective in preventing shoaling than was plan 17C. This decrease in effectiveness was attributed to the change in the shoreward arm alignment of the plan-21 breakwater from that of plan 17C.

Current-direction tests

89. Since plan 21 was less effective than plan 17C, due to the plan-21 breakwater alignment, a few arrangements of the north-south spurs at the navigation opening were tested to devise a satisfactory plan using the

plan-21 alignment. Various lengths of spurs were installed on either side of the navigation opening and clear water current-direction tests were made to determine their effectiveness in deflecting ebb-tide currents away from the navigation opening and problem area. The most favorable arrangement was found to be a single north-south spur breakwater 400 ft long attached to the east side of the navigation opening (plate 60). This modification of the plan-21 breakwater was designated plan 21A.

Results of tests -- plan 21A

90. Plan 21A effected greater reduction in shoaling than did plan 21. In general, the location and outline of silt deposition were about the same for both plans, but the amount of shoaling was less for plan 21A. The improved effectiveness of plan 21A was attributed to the reduced width and velocity of silt-bearing currents entering the navigation opening. On the basis of shoaling indices, plan 21A compared favorably with plan 17C in the reduction of shoaling. Shoaling results of plans 21 and 21A are shown on plates 71 and 72.

Tests to Determine Top Elevation of Breakwater

Purpose of tests

91. These tests were conducted to determine the minimum elevation to which the two arms of the proposed breakwater could be constructed and still provide sufficient protection to the harbor area from overtopping storm waves. At the outset of the model investigation, the plans which had been devised by the Navy Department had top elevations for the breakwaters of +12 ft mllw. The proposed plans were tested in the model using

maximum wave conditions to which the prototype breakwater would be subjected. Eye witnesses stated that 10-ft-high waves had been observed in the vicinity of the problem area, and tide records showed that the water level during storms had reached an elevation as high as +9.6 ft mllw. These conditions were selected for testing all plans to determine their effectiveness in reducing wave action in the problem area. Thus it was found that the +12 ft mllw top elevation, as originally devised, was inadequate in that the 10-ft-high test waves, together with the +9.6-ft water level, caused overtopping of the model breakwater to such an extent that the effect of small differences in breakwater plans could not be detected.

92. For purposes of model testing, the top elevation of the breakwaters was raised to +17 ft mllw. This prevented overtopping and allowed the effects of width and position of navigation opening, breakwater alignment, etc., to be determined. The +17-ft top elevation was selected arbitrarily, however, and it was not thought that the prototype breakwater would have to be constructed to such a high elevation to give sufficient protection to the problem area. It was considered desirable, therefore, to test plans using different breakwater elevations to determine the minimum elevation which would be satisfactory.

Plans tested

93. Plan 18B was selected for use in these tests. This plan, as originally tested in the wave height tests, had a top elevation of +17 ft for both arms of the breakwater. Two modifications of the plan were tested in this series of tests, and were designated plans 18G and 18H. For plan 18G the top elevation of the bay arm and the west half of the

shoreward arm was +17 ft, with the remainder of the shoreward arm at an elevation of +12 ft mllw. For plan 18H the bay arm was at a top elevation of +17 ft, and all of the shoreward arm was at an elevation of +12 ft. Elements of these plans are shown on plates 9 and 10.

Results of tests

94. The results of these tests are shown in table 2 and on plates 43-45. These data indicate that top elevations of +17 ft for the bay arm, and +12 ft for the shoreward arm of the breakwater would provide sufficient protection to the harbor even from the most severe storms which occur in that area of San Francisco Bay. For the most severe storm conditions, some overtopping of the shoreward arm of the breakwater would occur, but it is thought that resulting waves in the harbor area would not be objectionable considering the infrequency of such storm conditions.

Discussion

95. In view of the fact that both a relatively high still-water level and a rather large primary wave were used for testing in the model, the problem of determining the optimum height of the breakwater probably should be approached from a rational point of view as well as from the results of model tests. A rational solution of this problem involves determination of the height of waves which can be propagated toward the problem area due to wind, considering the mean water level which would obtain during storm conditions. Stevenson's empirical formula for maximum wave heights in the case of a strong gale, and when the water depth is sufficient to allow the waves to be fully formed, is

$$h^2 = 2.25 F, \quad (\text{Eq. 1})$$

and for short fetches and violent squalls,

$$h = 1.5 \sqrt{F} + (2.5 - \sqrt[4]{F}), \quad (\text{Eq. 2})$$

in which h is height of waves in feet, crest to trough, and F is the fetch in nautical miles. Applying these formulae to the southern portion of San Francisco Bay which, measured from the Alameda Naval Air Station, has an effective fetch of about 15 miles southward, maximum wave heights of 5.8 ft and 6.4 ft are obtained for formulae 1 and 2, respectively.

96. During the storm of 11 February 1941, several observations of high-water level were made in San Francisco Bay near the Alameda Naval Air Station, and a high elevation of +9.6 ft mllw was observed in the vicinity of the problem area and at the San Francisco airport. Tide records from the U. S. Coast and Geodetic Survey tide gage at Alameda Naval Air Station showed a high elevation of +8.7 ft mllw during this storm. Tide tables published by the U. S. Coast and Geodetic Survey indicate that the high tide range at the Alameda Naval Air Station is from +4.0 to +7.2 ft mllw. If complete protection is desired for extreme conditions of high waves and high water, it would be necessary to use a +9.6-ft mllw level for calculating the height of the breakwater. However, if some overtopping could be tolerated at infrequent intervals, the normal high tide of +7.2 ft mllw could be used.

97. An expression for determining the height of a sloping mound breakwater was developed by Mr. M. M. Catena. This formula gives the height of breakwater above the undisturbed water surface (mean level of wave) as $1.25 h$, where h is wave height. Using this formula with a +9.6-ft water level and a 10-ft wave height, a required top elevation of +22.1 ft is obtained. Experience with breakwaters along the coast of

California and elsewhere indicates that this elevation is considerably higher than is necessary for practical purposes. Also, model test results showed that the breakwater would not have to be this high. Thus, it is believed that either the 10-ft wave height or the +9.6-ft water surface, or both, are higher than necessary for use in determining breakwater height to assure a harbor safe from storm wave action.

98. Considering the dimensions of San Francisco Bay, it is believed that a wave height of 6.5 ft is more nearly the size wave for which the breakwater should be designed to prevent overtopping. Also, it is believed that a water-surface elevation of +7 ft mllw would represent conditions which occur with sufficient frequency to justify complete protection from overtopping. Using these values, Stevenson's wave height formula for short fetches and squalls, and the Catena formula, a breakwater elevation of +15 ft mllw is obtained. On the basis of this analysis and the model tests to determine optimum height of breakwater, it is thought than a +15-ft mllw top elevation for the bay arm, and a +12 ft mllw top elevation for the shoreward arm of the breakwater would be sufficient.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

ConclusionsCauses of the problem

99. It was concluded from the study of prototype data that the causes of the problem were the local storm waves which approach the Alameda Air Station from about the southwest direction, and the deposition of silt material in the problem area. It was thought that this material was being transported in suspension by ebb-tide currents from the mud flats situated between about the -10-ft mllw contour and the shore line southeast of the Air Station.

Protection from waves

100. Plans 4-15 provide about the same general protection to the harbor. All of these plans except plan 14 satisfy aircraft operational requirements. Location of the navigation opening in the shoreward arm of the plan-14 breakwater would result in difficulties to taxiing aircraft and might prevent any alleviation of the shoaling problem. Plan 4A, using the shoreward arm alignment of plan 15, will provide as good protection from waves as any of the other plans tested in this investigation. Should more protection be desired, the additional elements of plans 9 and 15 could be added. Plans 17C and 18B appeared to provide adequate protection to the problem area from storm waves. The elements of plans 17C and 18B were identical except that plan 17C had a 750-ft navigation opening whereas the plan-18B opening was 500 ft in width. The choice between these two plans should be determined from practical considerations

regarding the width of navigation opening necessary to satisfy aircraft operational requirements. Plans 19 and 20 are not considered to be of any practical value except for some slight protection from waves from the south direction.

Protection from shoaling

101. All plans tested were effective in the prevention of shoaling. The best of the plans reduced shoaling in the problem area about 90 per cent. Plan 18B is thought to be the best over-all plan investigated. However, plan 17C allowed only a slightly greater amount of shoaling than plan 18B.

Protection from waves and shoaling

102. Plan 21 was selected for testing with respect to protection from both wave action and shoaling. It was found that this plan would afford adequate protection from storm waves, but that it was about 17 per cent less effective than plan 17C with respect to shoaling. Plan 21A was developed to increase the effectiveness of plan 21 in reducing shoaling. This slight change in the elements of plan 21 did not change its effectiveness in the reduction of waves.

Height of breakwaters

103. Although most of the plans tested in the wave-height investigation had top elevations of 17 ft mllw, this height is not believed necessary for the prototype breakwaters. Top elevations of +15 ft and +12 ft mllw for the bay and shoreward arms, respectively, are considered sufficient to provide the desired protection from overtopping waves. Lower top elevations for the breakwater would also be less hazardous to landing seaplanes.

Recommendations

104. It was recommended that a plan similar to plan 21A, using top elevations of +15 ft mllw for the bay arm and +12 ft mllw for the shoreward arm, be considered for construction in the prototype harbor.

Breakwater Constructed in Prototype

105. A plan very similar to plan 21A of this report was selected for construction in the prototype. Construction of the breakwater was begun in the latter part of 1945 and completed in April 1947.

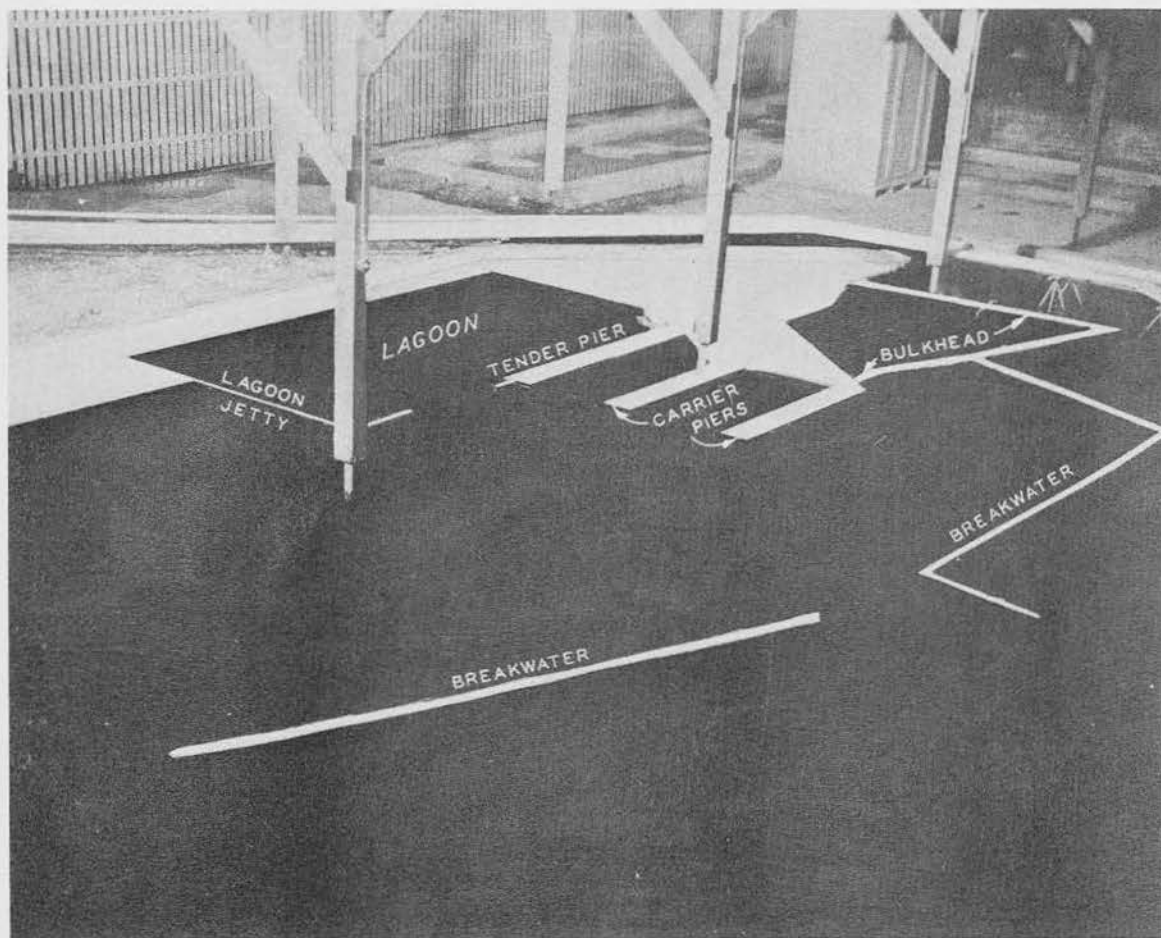


Fig. 9. General view of model with plan 21A installed

TABLES

TABLE 1
BREAKWATER LENGTHS

Plan	Breakwater Length	Plan	Breakwater Length
1	4,050	11	12,730*
2	8,160	12	12,690*
2A	8,410	13	10,560
2B	8,660	14	10,560
2C	9,160	15	7,360
4	8,680*	16	9,490
4A	8,930*	17	8,620
4B	9,180*	17A	8,920
4C	9,680*	17C	9,120
5	8,160	18	8,850
5A	8,410	18A	9,150
5B	8,660	18B	9,350
5C	9,160	19	6,450
6	10,930*	20	7,150
7	12,930*	21	6,930
8	14,930*	21A	6,830
9	12,480*	22	6,930
10	12,780*		

* Alignment of the shoreward arm of the breakwater to include the area for future expansion to the east of the turning basin increases the length of the shore arm of the breakwater by about 2400 ft.

TABLE 2

WAVE HEIGHTS

Base Test and Plans as Shown: Waves from South

Plan	Gage Number and Location																			
	Lagoon				Turning Basin				Bay Area											
	1	2	3	4	5	6	10	11	7	8	9	12	13	14	15	18	21	22	23	24
Base Test	5.5	2.5	2.0	8.5	6.0	8.0	11.0	9.5	10.0	15.0	13.5	7.0	16.0	10.0	12.0	20.0	10.0	9.0	5.0	5.0
1	4.0	2.5	2.0	6.0	6.0	7.0	9.0	7.5	4.5	14.5	12.0	7.0	15.0	9.5						
2	3.5	2.0	1.5	4.5	4.0	7.0	10.0	6.0	5.5	15.0	12.5	5.0	17.0	10.0						
2A	2.5	1.5	1.0	4.0	5.0	5.0	8.0	4.0	4.5	15.0	11.5	4.5	17.0	10.0						
2B	2.0	1.0	1.0	4.0	4.5	4.5	7.0	4.5	4.0	15.0	12.0	4.5	14.0	10.5						
2C	1.5	0.5	0.5	3.0	3.5	3.0	5.5	4.0	3.0	12.0	12.0	4.5	14.0	10.0						
4	2.5	0.5	0.5	4.0	4.5	6.0	7.0	4.0	3.0	15.0	14.0	4.0	16.0	8.0						
4A	2.0	0.5	0.5	4.0	3.5	5.0	6.0	4.0	2.0	15.0	14.0	3.0	17.5	10.0						
4B	1.0	0.5	0.5	3.0	3.5	4.5	6.0	3.5	1.5	18.0	14.0	4.0	17.0	9.5						
4C	0.5	0.5	0.5	1.5	2.0	2.0	3.0	3.5	1.0	17.5	12.0	4.0	17.5	10.0						
5	3.0	1.0	0.5	4.0	5.0	5.0	9.0	5.0	4.5	17.0	15.0	4.0	18.0	10.0						
5A	2.5	0.5	0.5	3.5	4.0	4.5	7.0	4.0	3.5	17.0	15.0	4.0	16.0	9.0						
5B	2.0	0.5	0.5	3.0	3.0	4.0	4.5	3.5	3.0	17.0	15.0	4.0	16.0	10.0						
5C	0.5	0.5	0.5	1.5	2.5	2.5	2.5	3.5	2.0	16.5	15.5	4.0	16.0	10.0						
6	1.5	0.5	0.5	3.0	3.5	5.0	6.0	5.0	2.0	15.0	13.0	4.5	16.0	8.5	13.0					
7	1.5	0.5	0.5	2.0	3.5	4.5	5.5	5.5	2.0	15.0	13.0	3.5	14.0	4.5		15.5				
8	1.0	0.5	0.5	2.0	3.5	4.0	5.5	4.5	2.0	15.0	14.0	2.5	17.0	4.0		9.5				
9	1.0	0.5	0.5	2.0	3.0	4.5	7.0	6.5	2.0	14.0	13.5	5.5	16.0	7.0	11.5					
10	1.0	0.5	0.5	2.5	3.0	5.0	6.5	6.0	2.0	15.0	14.0	5.5	6.0	6.5		15.5				
11	1.5	0.5	0.5	2.5	3.5	4.0	7.0	6.0	2.0	14.0	14.0	4.5	6.5	7.0		15.5				
12	1.5	0.5	0.5	2.5	3.5	4.5	7.0	6.5	1.5	14.0	13.0	6.0	6.5	7.0		15.5				
13	1.5	0.5	0.5	2.5	4.0	5.5	7.0	4.0	3.5	15.0	14.0	4.0	17.0	4.0		15.5				
14	1.0	0.5	0.5	1.5	3.0	4.0	4.0	3.5	5.5	14.0	14.0	4.0	17.0	4.0		15.5				
15	2.0	0.5	0.5	4.0	3.0	3.0	6.0	3.0	2.5	13.0	13.0	4.0	16.0	10.0						
17C	1.5	1.0	0.5	3.0	3.5	5.5	6.5	5.0	3.0	15.0	13.5	4.5	17.0	10.0						
18B	1.5	0.5	0.5	2.0	3.5	4.0	5.0	3.5	2.0	15.0	15.0	5.0	16.0	9.0			6.5	3.0	2.0	2.0
18C	1.5	0.5	0.5	2.5	4.0	5.0	5.0	4.0	2.5	16.0	15.5	5.5	16.0	9.5			7.5	3.5	3.0	2.0
18H	2.0	0.5	0.5	3.0	4.0	5.0	5.5	4.5	2.5	15.0	15.0	5.5	16.0	9.0			8.0	4.0	4.0	3.0
19	4.0	2.0	1.5	7.0	5.5	8.0	10.5	9.0	3.5	14.5	12.5	7.0	15.5	10.0						
20	4.0	2.0	2.0	6.5	5.0	6.0	6.5	8.5	5.0	16.0	14.5	7.5	15.0	10.0						

NOTES: Wave heights in feet (prototype) to nearest 0.5 ft.

Test conditions were as follows:

- a. Model represents prototype conditions as of March 1943.
- b. Wave height in problem area approximately 10 ft.
- c. Water-surface elevation + 9.6 ft mllw.

TABLE 3

WAVE HEIGHTS

Base Test and Plans as Shown; Waves from South 20° West

Plan	Gage Number and Location																			
	Lagoon				Turning Basin				Bay Area											
	1	2	3	4	5	6	10	11	7	8	9	12	13	14	15	16	21	22	23	24
Base Test	4.5	3.0	2.5	7.0	6.0	9.0	10.0	11.0	9.0	13.5	14.0	7.5	14.0	13.5	19.0	20.0				
1	4.0	2.5	2.0	6.5	5.5	7.0	10.0	10.5	5.0	13.5	14.0	6.5	14.0	13.5						
2	3.5	1.5	1.5	6.0	5.0	7.0	8.0	7.0	6.0	13.0	15.0	6.5	15.0	11.0						
2A	4.0	1.5	1.5	5.0	5.0	7.0	8.0	7.0	5.0	13.0	14.5	6.5	14.0	13.5						
2B	3.0	2.0	1.5	5.0	5.0	6.5	6.5	6.0	4.5	15.0	14.0	6.5	14.0	14.0						
2C	2.0	1.0	0.5	3.5	4.0	4.0	6.0	6.0	4.0	14.5	14.0	6.0	13.0	14.0						
4	3.0	1.5	1.5	4.0	4.5	6.0	9.0	7.0	4.0	17.0	16.0	6.0	17.0	14.0						
4A	3.0	1.5	1.5	4.0	4.5	5.0	8.0	6.5	3.0	16.0	17.0	7.0	16.0	14.0						
4B	3.0	1.5	1.0	4.0	3.5	5.0	7.5	6.5	3.0	17.0	17.0	7.0	16.0	14.0						
4C	2.0	1.0	0.5	2.5	2.5	4.0	4.5	5.0	3.0	17.0	17.0	7.0	15.0	14.0						
5	3.0	0.5	0.5	4.5	5.0	6.5	7.0	6.0	6.5	17.0	14.5	7.0	14.0	12.0						
5A	2.5	0.5	0.5	3.5	4.5	5.0	6.0	5.5	4.0	17.0	16.0	6.5	14.0	12.5						
5B	2.0	0.5	0.5	3.0	3.5	5.0	5.5	4.0	3.0	16.0	16.0	5.5	14.0	12.0						
5C	1.0	0.5	0.5	1.5	2.5	3.5	3.0	3.5	2.5	17.0	16.0	5.5	14.0	12.0						
6	3.0	0.5	0.5	5.5	4.5	4.0	6.0	5.5	3.0	16.0	16.0	4.5	15.0	12.0	15.5					
7	2.5	0.5	0.5	5.0	3.0	3.5	6.5	4.0	2.0	16.0	15.0	4.5	16.0	8.0		18.0				
8	2.0	0.5	0.5	3.0	2.0	3.0	6.5	4.5	1.5	16.0	14.0	3.5	16.0	5.0		8.5				
9	2.5	0.5	0.5	4.5	2.0	3.0	7.5	3.0	2.0	13.0	14.0	5.0	14.0	8.5	14.0					
10	2.0	0.5	0.5	5.0	2.5	3.5	7.5	3.5	2.0	15.0	14.0	5.0	5.5	8.0		19.0				
11	2.0	0.5	0.5	5.5	3.0	3.0	8.0	4.5	2.0	14.0	13.0	5.0	6.0	9.5		19.0				
12	2.5	0.5	0.5	5.5	3.5	4.5	8.0	5.0	2.0	15.0	16.0	5.5	8.5	7.0		17.0				
13																				
14																				
15																				
17C	3.5	1.5	1.5	5.0	5.0	4.0	6.5	6.0	4.0	12.0	13.0	7.0	14.0	12.5						
18B	3.0	1.5	1.5	3.0	3.5	3.0	6.0	6.0	2.5	14.0	14.0	8.0	17.0	13.0						
18G																				
18H																				
19	4.0	2.5	2.5	6.5	5.5	8.0	9.0	10.5	4.0	14.0	13.0	7.5	14.0	13.5						
20	3.5	3.0	2.0	5.5	5.0	7.0	9.5	10.5	3.5	14.0	12.0	7.5	15.0	11.5						

NOTES: Wave heights in feet (prototype) to nearest 0.5 ft.

Test conditions were as follows:

- a. Model represents prototype conditions as of March 1943.
- b. Wave height in problem area approximately 10 ft.
- c. Water-surface elevation + 9.6 ft mllw.

TABLE 4

WAVE HEIGHTS

Base Test and Plans as Shown: Waves from Southwest

Plan	Gage Number and Location																			
	Lagoon				Turning Basin				Bay Area											
	1	2	3	4	5	6	10	11	7	8	9	12	13	14	15	18	21	22	23	24
Base Test	4.5	4.0	3.0	8.5	7.0	11.5	12.0	12.0	11.0	15.0	18.0	12.0	15.0	17.0	19.0	23.0				
1	4.0	4.0	3.0	7.0	6.0	11.5	11.0	12.0	8.0	15.0	18.0	10.5	16.5	17.0						
2	3.0	2.0	1.5	5.0	5.0	6.5	6.5	8.5	5.5	13.0	18.0	8.0	14.5	16.0						
2A	3.0	2.0	1.5	5.0	5.0	6.0	8.0	7.5	6.0	13.0	19.0	8.5	16.0	17.0						
2B	3.0	2.0	1.5	5.5	4.5	6.0	8.0	9.0	5.0	13.0	19.0	9.0	16.0	18.5						
2C	2.0	1.5	1.5	5.0	4.5	5.0	6.0	7.5	3.5	14.0	17.0	8.0	16.0	18.0						
4	1.0	1.0	0.5	4.0	5.0	6.5	8.5	8.5	5.0	15.0	19.0	11.5	17.5	16.0						
4A	2.0	1.0	1.0	4.0	5.0	5.5	8.0	7.5	4.5	16.0	18.0	11.0	17.0	17.5						
4B	1.5	1.0	0.5	4.0	5.0	5.0	7.5	7.5	3.5	16.0	18.0	11.0	17.0	17.5						
4C	1.0	1.0	0.5	4.0	5.0	5.0	7.5	7.0	2.0	17.0	18.0	11.0	17.5	18.5						
5	2.0	1.0	0.5	3.0	5.0	6.5	7.0	8.0	4.5	15.5	18.0	7.5	16.5	16.5						
5A	1.5	0.5	0.5	2.5	5.0	6.0	6.0	8.0	4.5	16.5	18.0	7.5	17.0	16.5						
5B	1.5	0.5	0.5	2.5	4.5	5.0	5.5	6.0	4.5	17.0	19.0	7.0	15.5	16.5						
5C	1.0	0.5	0.5	2.5	4.0	5.0	5.0	6.0	2.5	15.0	18.5	6.5	16.0	16.0						
6	2.0	1.0	0.5	2.5	4.5	5.5	7.5	7.5	2.5	15.0	16.0	6.5	17.0	16.5	15.0					
7	1.5	0.5	0.5	2.0	3.0	5.5	6.5	6.0	2.5	15.0	16.0	6.5	17.0	11.0		22.5				
8	1.5	0.5	0.5	2.0	3.0	4.5	6.0	5.5	2.0	14.0	17.0	6.5	17.0	9.0		12.5				
9	1.5	0.5	0.5	3.0	3.5	3.0	7.0	4.5	2.0	16.0	15.0	6.0	16.0	13.0	17.0					
10	2.0	0.5	0.5	3.0	4.5	4.0	8.5	6.0	2.5	13.0	20.0	6.0	6.5	13.0		23.0				
11	2.0	1.0	1.0	4.0	5.5	5.0	8.5	6.0	2.5	13.5	19.0	7.5	8.5	13.0		21.0				
12	2.0	1.0	1.0	4.5	5.5	4.5	8.0	5.5	2.5	14.5	20.0	7.5	9.5	13.0		23.0				
13	1.0	0.5	0.5	3.0	4.5	4.5	5.5	4.0	3.5	15.0	16.0	5.0	16.0	11.0		22.0				
14	0.5	0.5	0.5	2.0	3.5	3.5	4.0	4.0	4.5	16.0	16.0	5.0	16.0	11.0		21.0				
15	1.5	0.5	0.5	3.0	5.5	5.0	5.0	5.5	4.5	15.5	17.0	4.5	15.0	17.0						
17C	2.0	1.0	1.0	3.5	5.0	6.0	8.0	10.0	5.0	14.5	17.0	11.5	17.5	17.0						
18B	1.5	1.0	1.0	3.0	5.0	5.5	7.5	9.0	3.5	15.0	15.0	11.0	17.0	17.0						
18H																				
18G																				
19	3.5	4.0	2.5	8.0	6.5	10.5	12.0	11.0	6.5	15.0	13.0	13.0	16.0	18.0						
20	3.5	4.0	2.0	7.5	6.0	9.0	12.0	11.5	6.0	16.0	18.0	13.0	16.0	17.0						

NOTES: Wave heights in feet (prototype) to nearest 0.5 ft.

Test conditions were as follows:

- a. Model represents prototype conditions as of March 1943.
- b. Wave height in problem area approximately 10 ft.
- c. Water-surface elevation + 9.6 ft mllw.

TABLE 5

WAVE HEIGHTS
Plans 21, 22, and Base Test

Wave Height in Problem Area Feet	Storm Direction	Water-Surface Elevation above mllw Feet	Plan	Gage Number and Location															
				Lagoon				Turning Basin						Bay Area					
				1	2	3	4	5	6	9	10	11	25	8	12	13	14	22	26
10	S	9.6	Base Test	5.0	2.5	2.0	10.0	6.0	8.0	14.0	11.0	10.0	10.0	15.0	9.0	16.0	10.0	11.0	13.0
			21	3.5	2.0	1.0	4.5	5.0	5.0	7.0	7.5	6.5	4.5	15.0	6.0	12.0	10.0	3.5	13.0
			22	1.5	1.0	0.5	3.5	5.0	4.0	6.0	5.5	5.5	2.5	15.0	5.0	12.0	10.0	2.5	14.0
7	S	7.0	Base Test	2.0	1.5	1.0	4.5	5.0	7.0	9.0	8.0	8.0	7.0	8.0	6.0	8.5	5.0	5.0	8.5
			21	1.5	0.5	0.5	2.5	2.0	2.5	3.5	5.0	4.0	1.5	8.0	3.0	5.0	5.0	1.0	8.5
			Base Test	4.0	2.5	2.0	8.0	7.0	10.0	13.5	10.0	11.0	9.0	13.0	8.0	14.0	13.0	10.0	14.0
10	S 20° W	9.6	21	2.5	1.5	1.5	4.0	5.5	6.5	9.0	6.0	9.0	6.0	14.0	7.5	13.5	12.5	3.0	15.0
			22	1.5	1.0	1.0	3.5	5.0	5.5	7.5	5.0	7.0	4.0	13.0	7.0	13.5	13.0	2.0	15.0
			Base Test	2.5	1.5	1.0	4.5	5.0	6.0	10.5	9.0	9.0	6.0	10.0	7.0	7.0	4.5	6.5	9.5
7	S 20° W	7.0	21	1.0	0.5	0.5	3.0	3.0	3.0	4.0	5.0	4.5	3.0	11.0	5.5	6.5	4.5	1.5	10.0
			Base Test	5.0	3.0	2.5	8.0	8.0	12.0	14.0	12.0	13.0	11.0	15.0	11.0	15.0	16.0	11.0	16.0
			21	2.0	1.5	1.0	4.5	7.0	8.0	9.0	8.5	8.5	7.0	15.0	10.5	15.0	15.5	3.5	15.0
10	S W	9.6	22	1.0	0.5	0.5	4.0	6.5	7.0	7.0	7.0	8.0	6.0	15.0	10.5	15.0	15.0	3.0	16.0
			Base Test	2.5	1.0	1.0	4.5	4.0	5.5	8.0	8.0	10.0	6.0	6.5	6.5	11.0	7.0	5.0	7.0
			21	1.0	0.5	0.5	3.0	3.0	3.5	3.0	4.0	3.0	2.0	6.0	6.0	11.0	7.0	2.0	7.0

NOTE: Tests conducted on revised model to include proposed additional docking facilities together with enlargement of turning basin.

TABLE 6
SHOALING INDICES

Preliminary Shoaling Tests of Plan 16 and "Base Test" Conditions and Comprehensive Shoaling Tests of Plans 17, 17A, 17C, 18, 18A, 18B, 19, 20, 21, 21A and "Base Test" Conditions

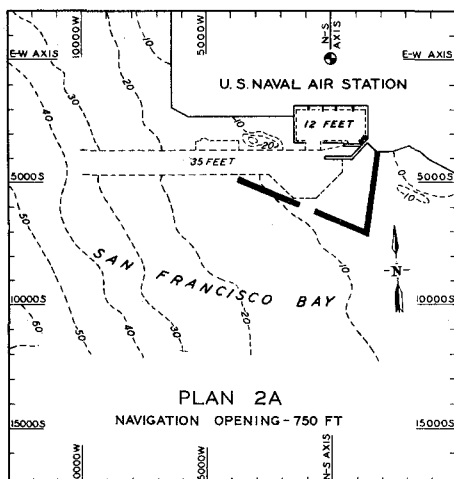
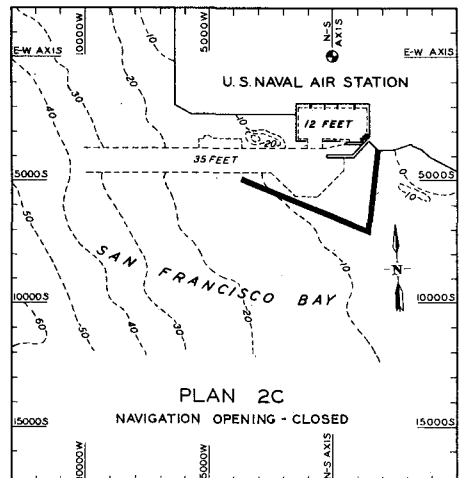
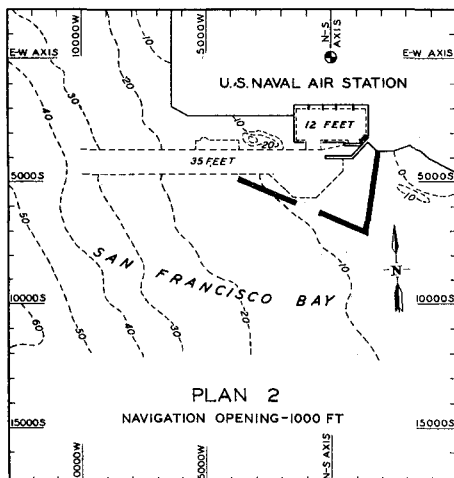
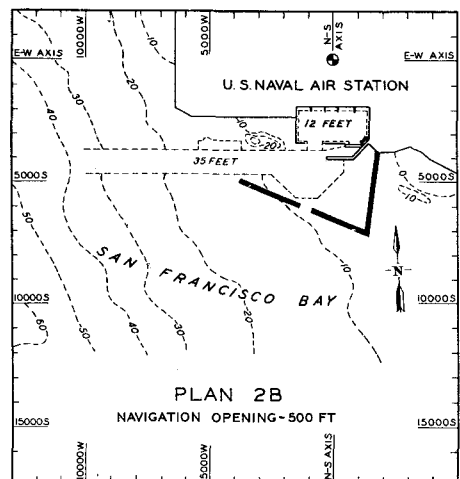
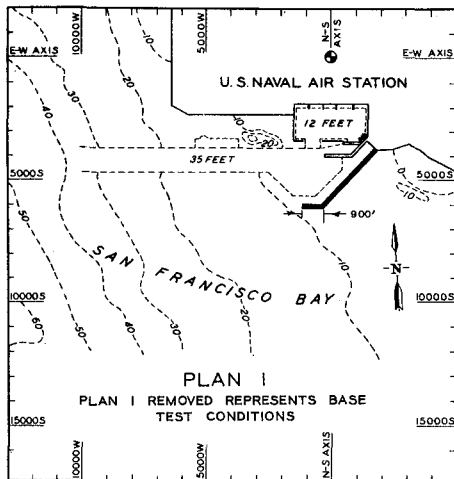
Plan	Area Number								Turning Basin	Entrance Channel
	1	2	3	4	5	6	7	8		
Base Test	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
16	0.00	0.00	0.08	0.00	0.08	2.35	0.15	0.00	0.14	0.00
Base Test	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
17	0.00	0.00	0.00	0.00	0.00	0.11	0.10	0.37	0.08	8.70
17A	0.00	0.00	0.03	0.03	0.12	0.76	0.27	0.00	0.12	0.00
17C	0.00	0.00	0.07	0.00	0.00	0.69	0.18	0.70	0.19	0.38
18	0.00	0.00	0.00	0.00	0.00	0.03	0.11	0.48	0.09	7.30
18A	0.00	0.00	0.00	0.03	0.06	0.02	0.26	0.00	0.05	0.00
18B	0.00	0.00	0.00	0.00	0.00	0.03	0.13	0.00	0.02	0.00
19	0.00	0.00	0.00	0.00	0.00	0.22	0.16	0.79	0.16	2.60
20	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.77	0.12	2.90
Plan	Area									
	The Problem Area -- Turning Basin and Entrance Channel									
Base Test	1.00									
21	0.36									
21A	0.22									

Notes: Shoaling tests of plans 16-20 and base tests were conducted with model representing prototype conditions as of March 1943.

Preliminary shoaling test of plan 16 was conducted prior to adjustment of model to reproduce the assumed ebb-tide current pattern in the vicinity of the breakwaters and these shoaling test results are not to be compared with those of other plans tested for reduction of shoaling. Shoaling tests of plans 17-21A were conducted with model adjusted to reproduce the assumed ebb-tide current pattern in the vicinity of the breakwaters.

Shoaling tests of plans 21 and 21A were conducted with revised model to include the proposed additional docking facilities together with enlargement of dredged turning basin.

PLATES



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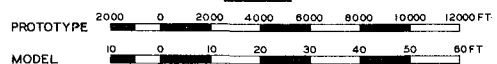
- PROPOSED BREAKWATER LOCATION
- 20- DEPTH IN FEET BELOW MEAN LOWER LOW WATER

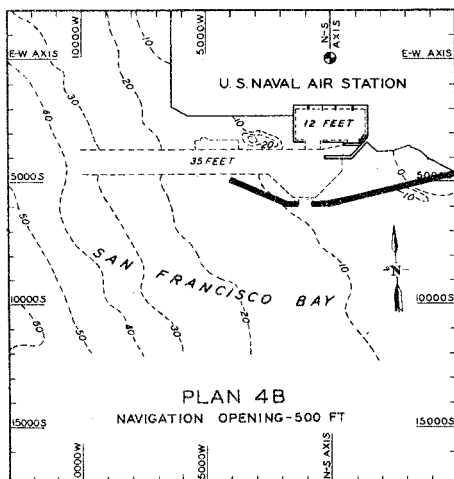
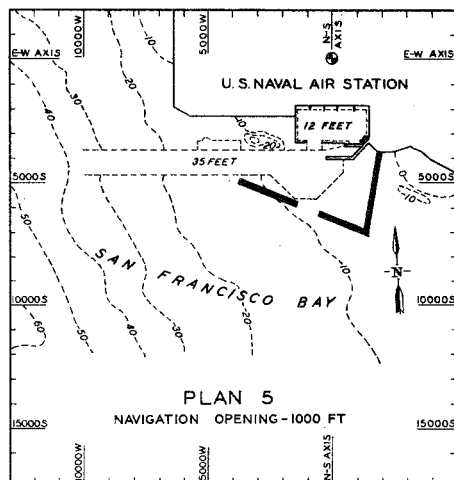
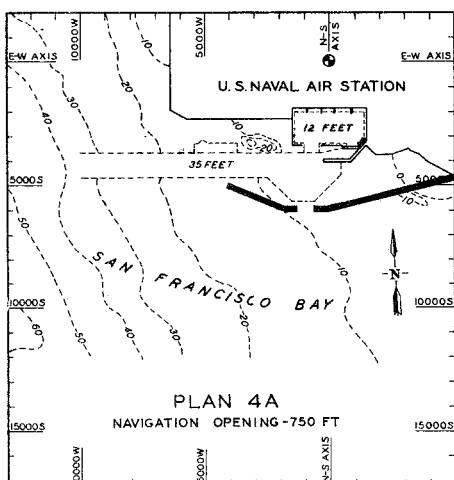
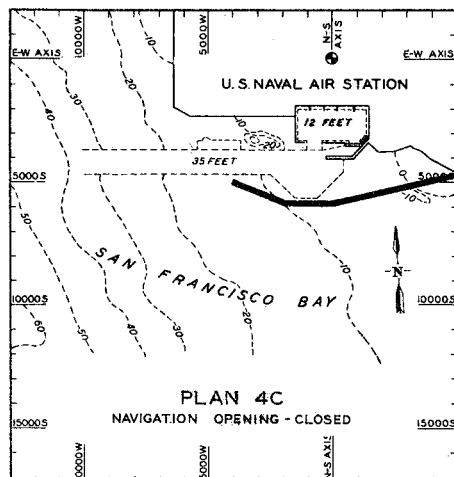
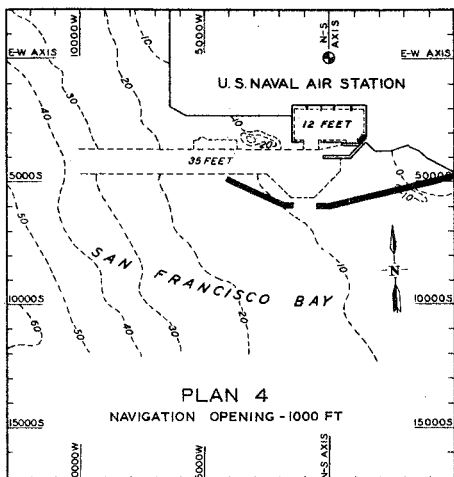
NOTE: TOP ELEVATION OF BREAKWATER IS +12.0 FEET, MEAN LOWER LOW WATER

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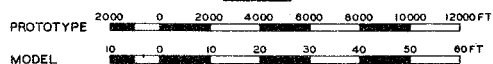
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- - - 20 - - - DEPTH IN FEET BELOW MEAN LOWER LOW WATER

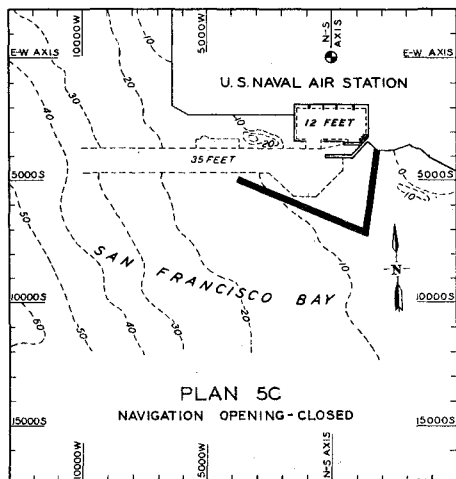
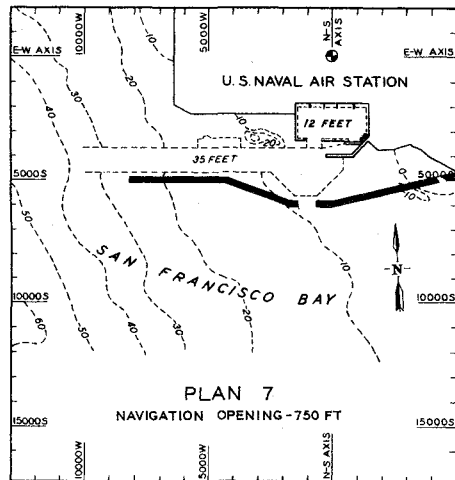
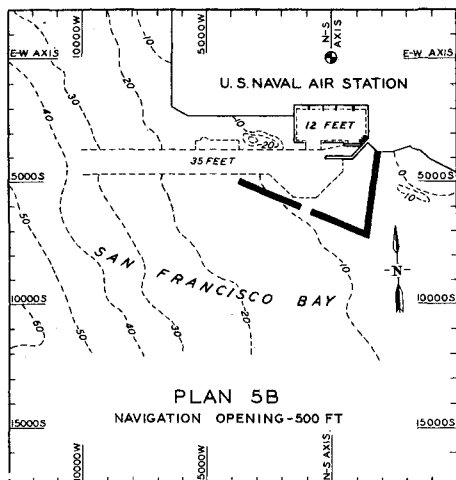
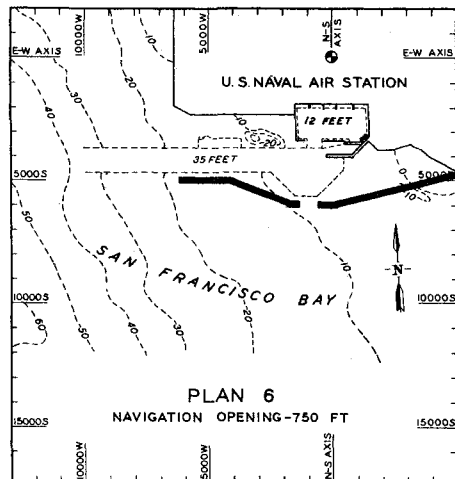
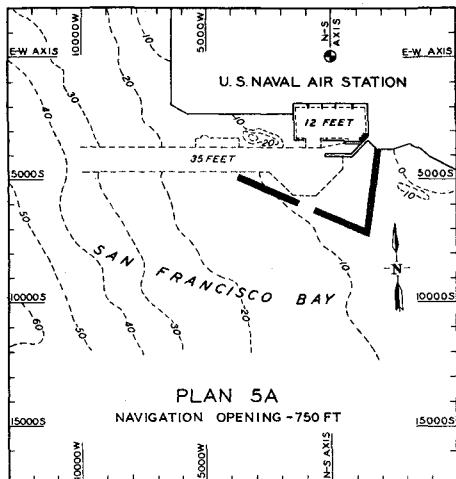
NOTE: TOP ELEVATION OF BREAKWATER IS
+17.0 FEET, MEAN LOWER LOW WATER

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- PROPOSED BREAKWATER LOCATION
- - - 20 - - - DEPTH IN FEET BELOW MEAN LOWER LOW WATER

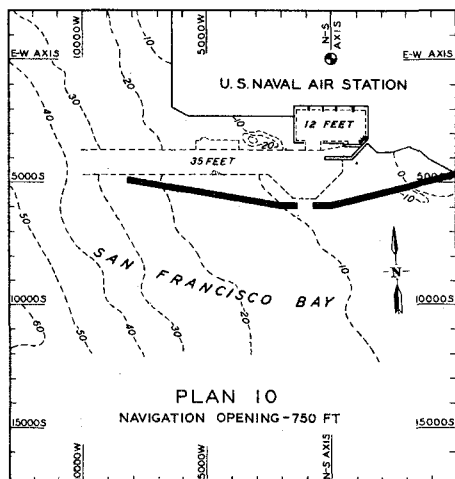
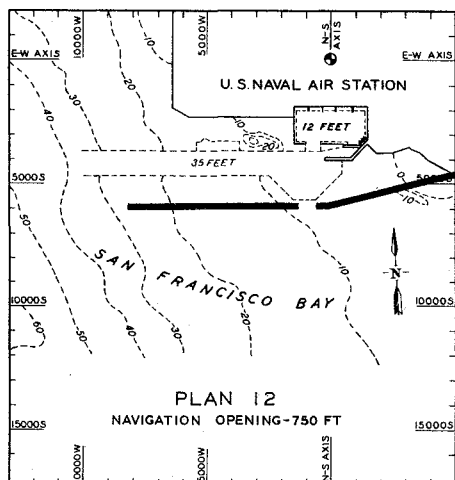
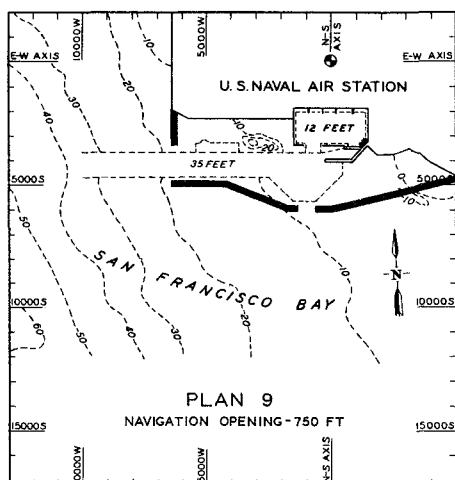
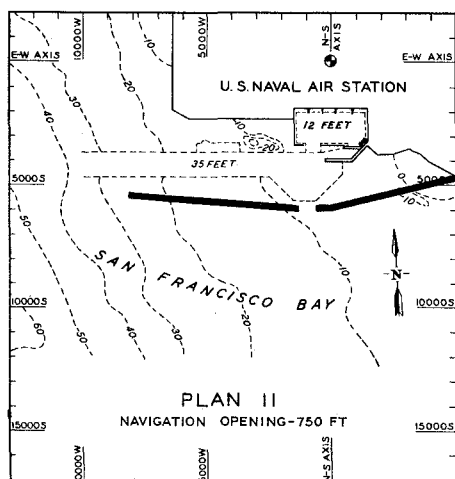
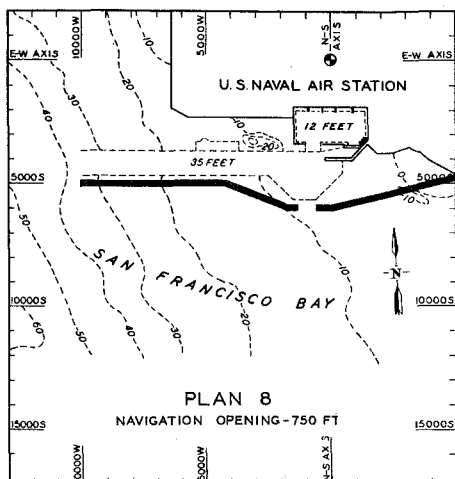
NOTE: TOPELEVATION OF BREAKWATER IS
+170 FEET, MEAN LOWER LOW WATER

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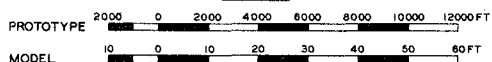
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- - - 20 - - - DEPTH IN FEET BELOW MEAN LOWER LOW WATER

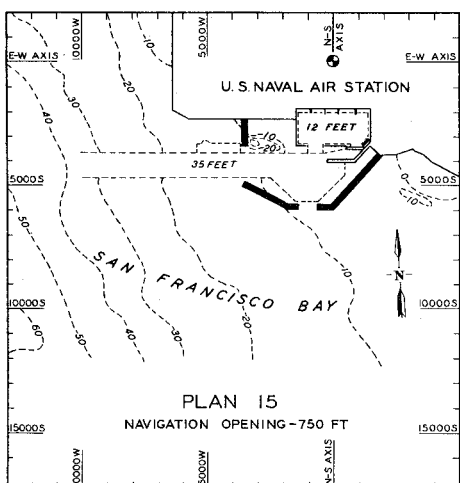
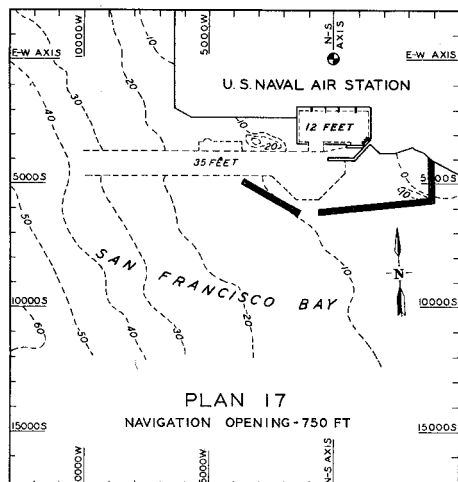
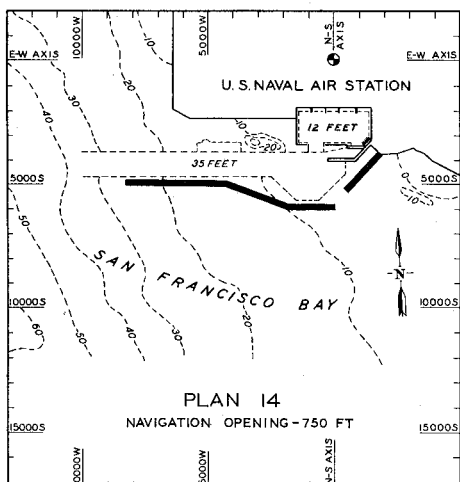
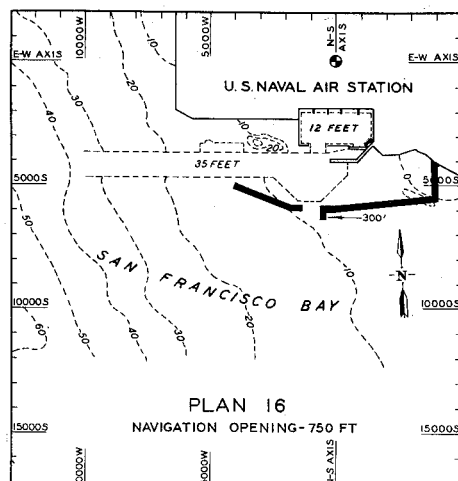
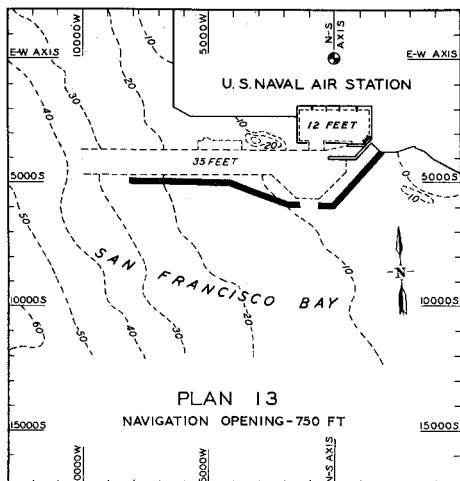
NOTE: TOP ELEVATION OF BREAKWATER IS
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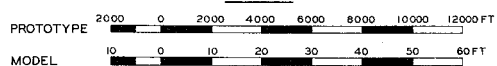
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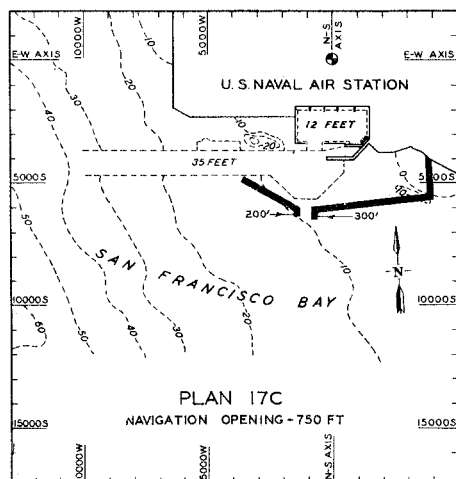
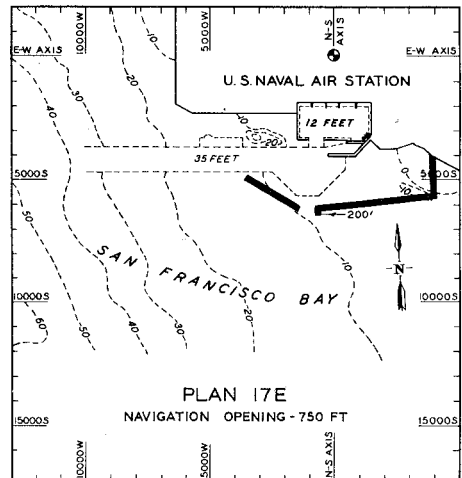
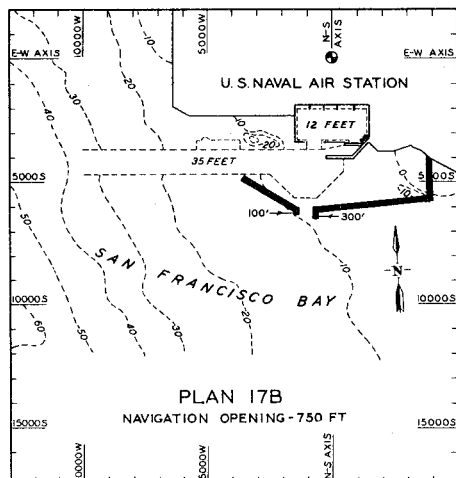
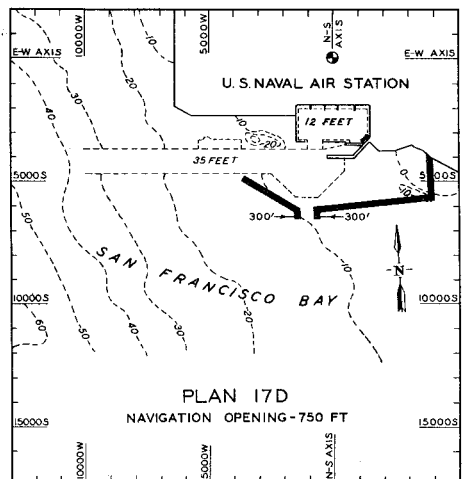
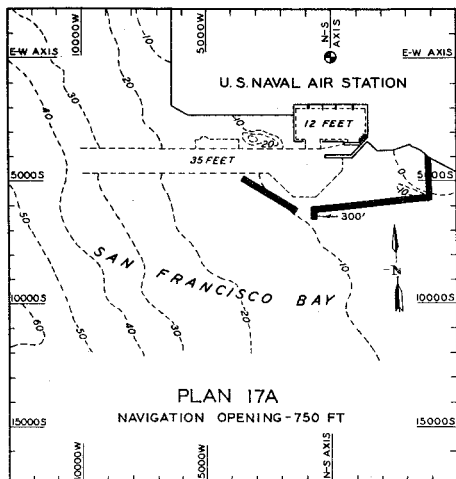
NOTE: TOP ELEVATION OF BREAKWATER IS
+170 FEET, MEAN LOWER LOW WATER

MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

ELEMENTS OF PLANS

SCALES





LEGEND

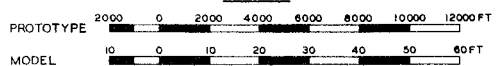
- PROPOSED BREAKWATER LOCATION
- - - 20 - - - DEPTH IN FEET BELOW MEAN LOWER LOW WATER

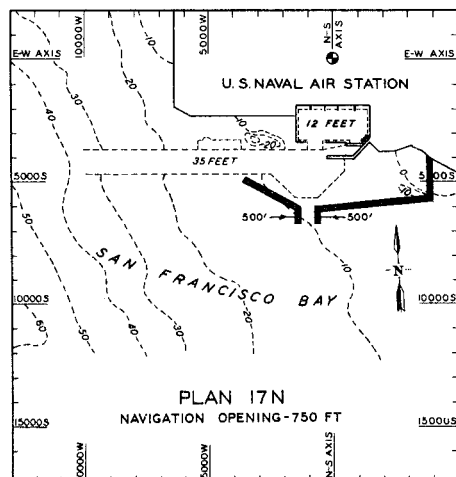
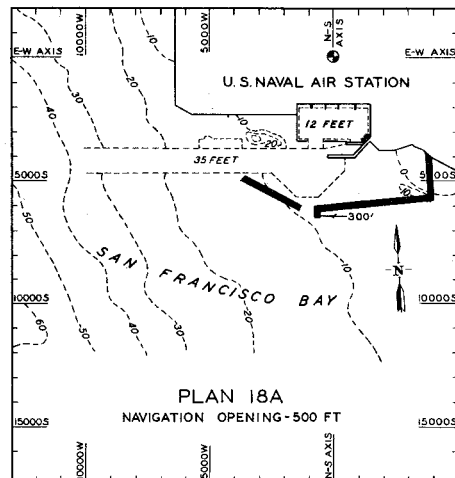
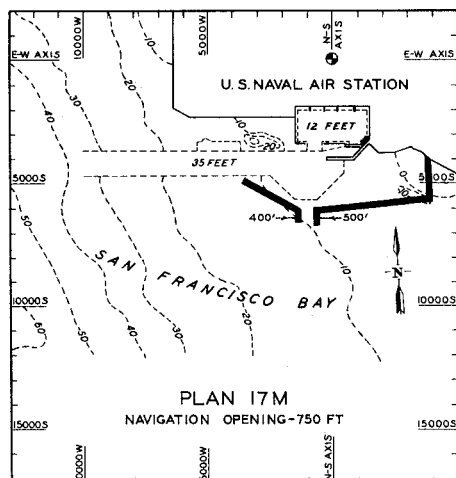
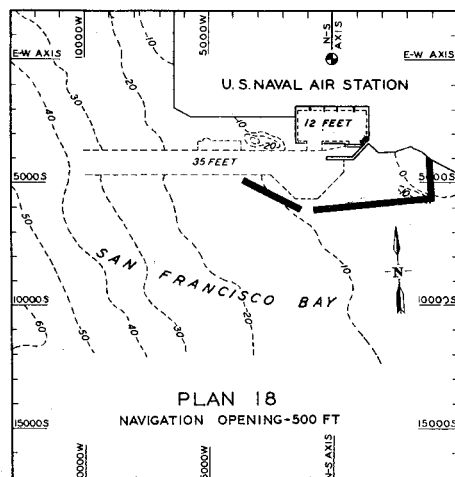
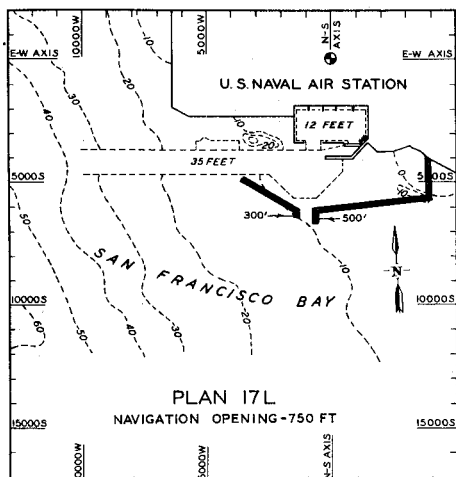
NOTE: TOP ELEVATION OF BREAKWATER IS +17.0 FEET, MEAN LOWER LOW WATER

MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

ELEMENTS OF PLANS

SCALES





LEGEND

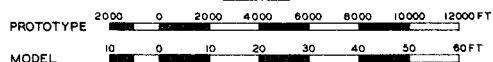
- PROPOSED BREAKWATER LOCATION
- - - 20 - - - DEPTH IN FEET BELOW MEAN LOWER LOW WATER

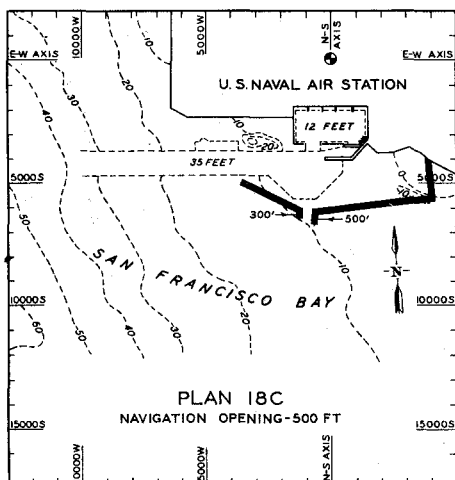
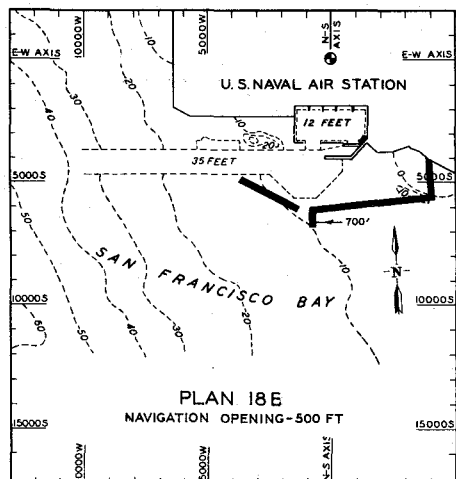
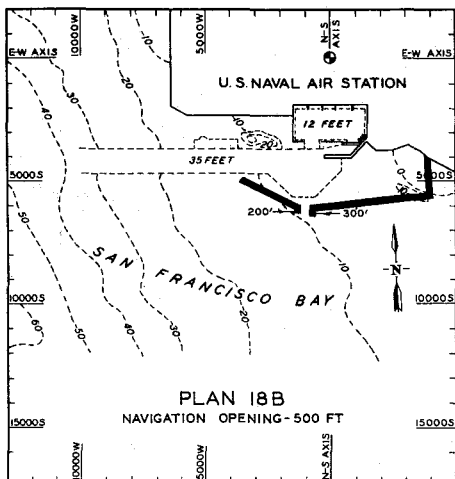
NOTE: TOP ELEVATION OF BREAKWATER IS
+17.0 FEET, MEAN LOWER LOW WATER

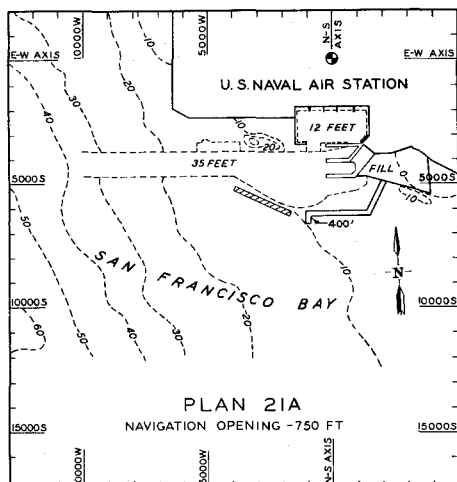
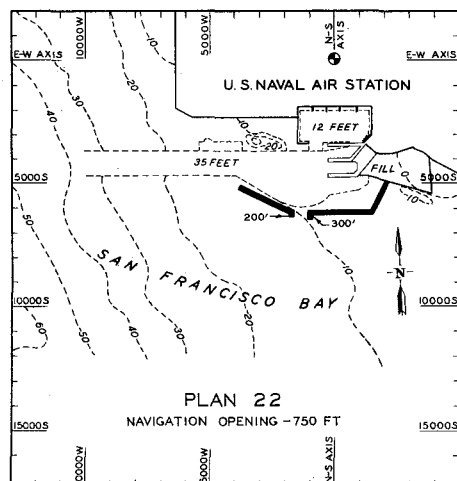
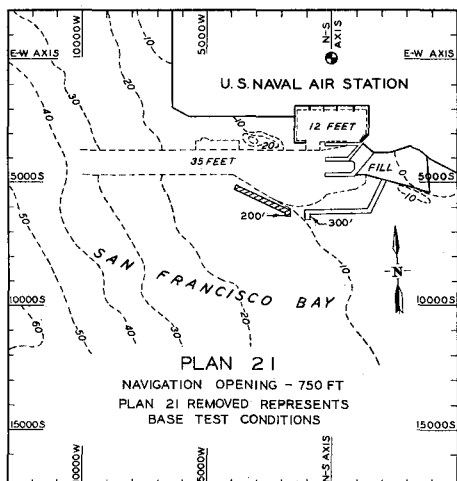
MODEL STUDY OF BREAKWATER LOCATION
U. S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

ELEMENTS OF PLANS

SCALES







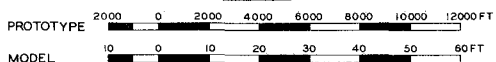
LEGEND

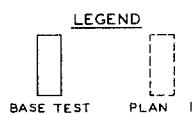
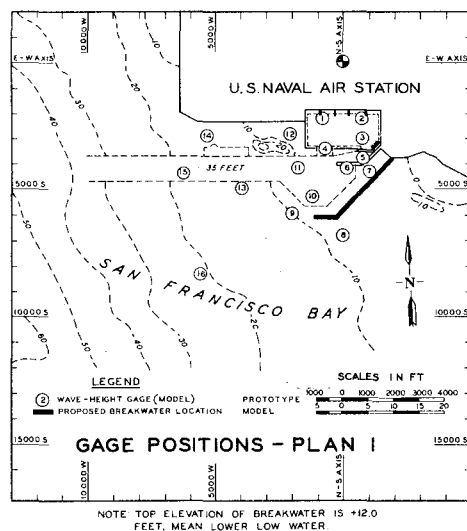
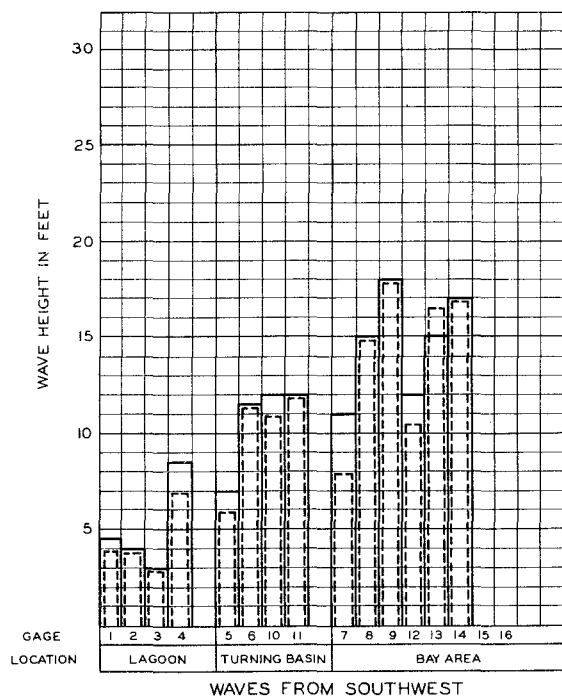
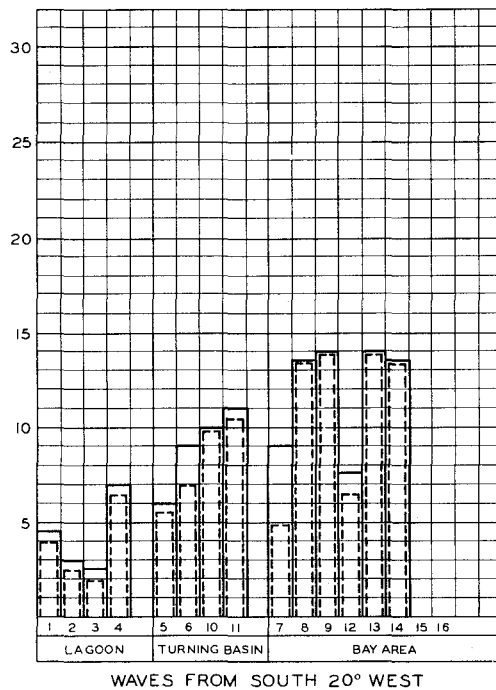
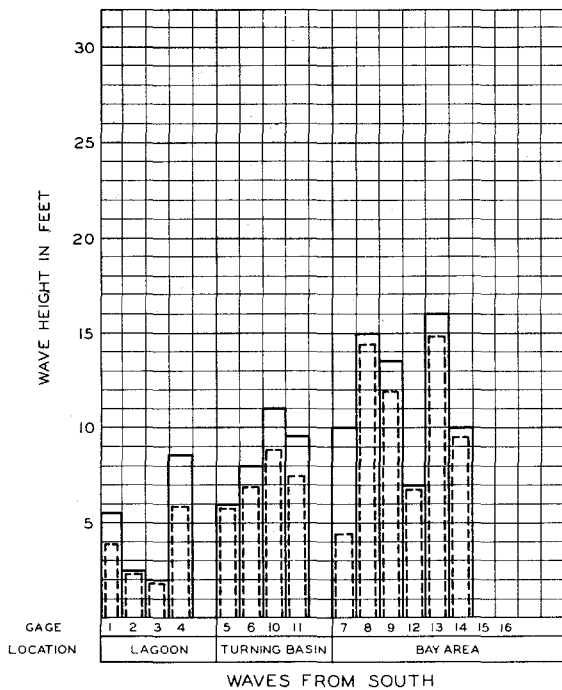
- PROPOSED BREAKWATER LOCATION (TOP ELEVATION + 17.0 FT MLLW)
- ▨ PROPOSED BREAKWATER LOCATION (TOP ELEVATION + 15.0 FT MLLW)
- PROPOSED BREAKWATER LOCATION (TOP ELEVATION + 12.0 FT MLLW)
- 20--- DEPTH IN FEET BELOW MEAN LOWER LOW WATER

MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

ELEMENTS OF PLANS

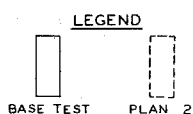
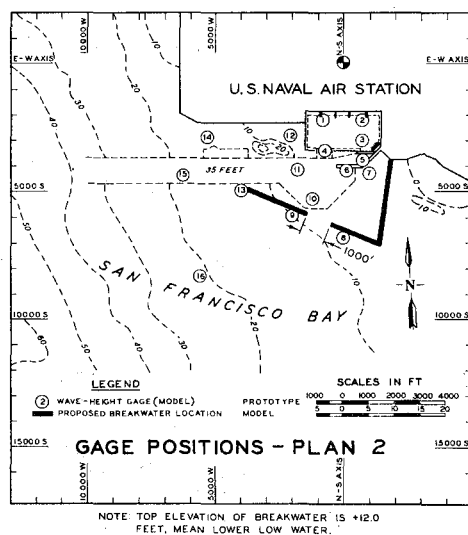
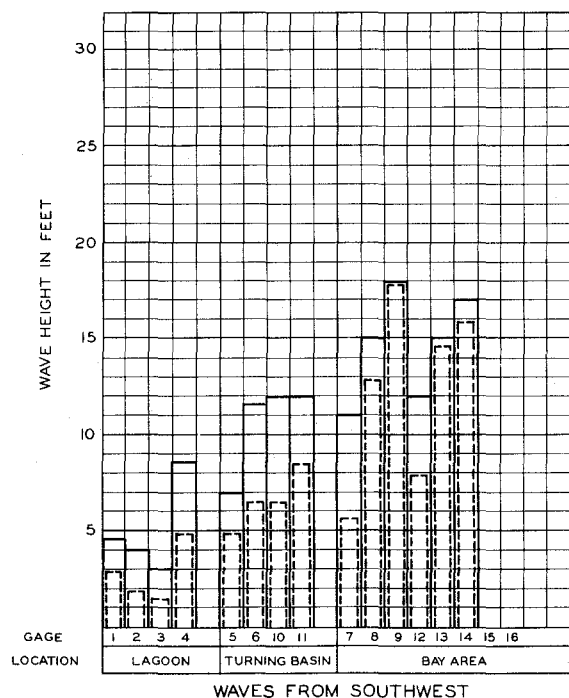
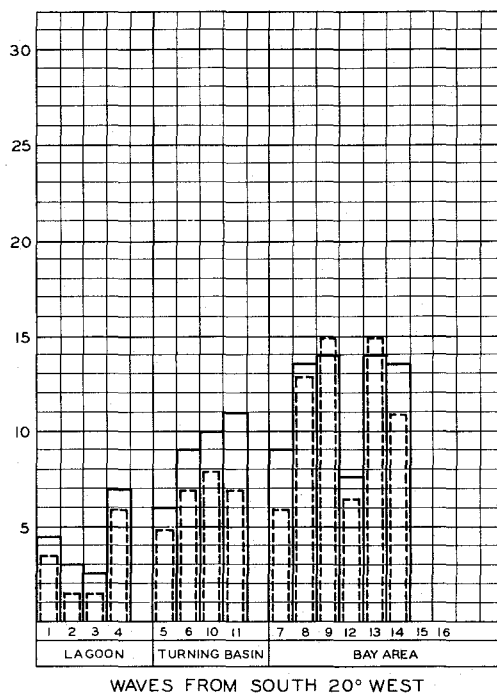
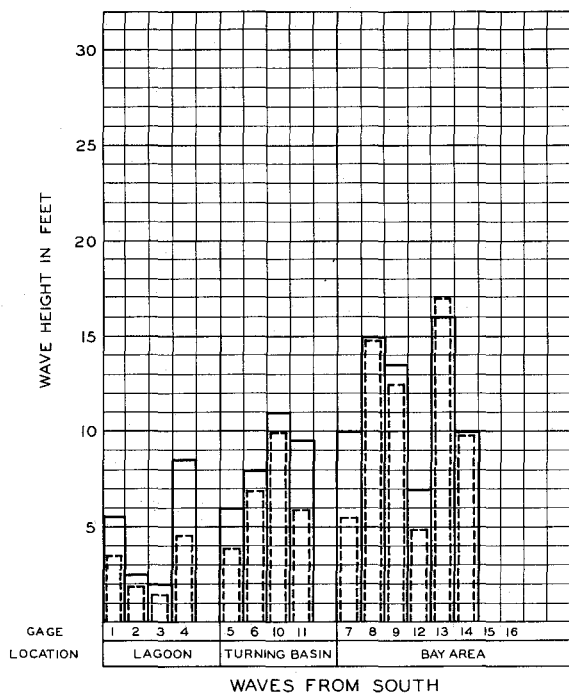
SCALES





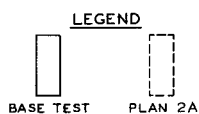
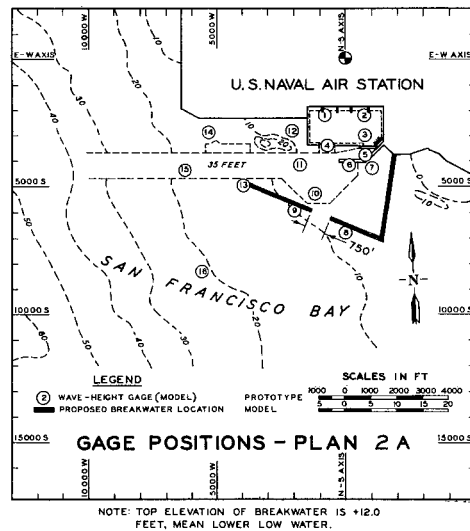
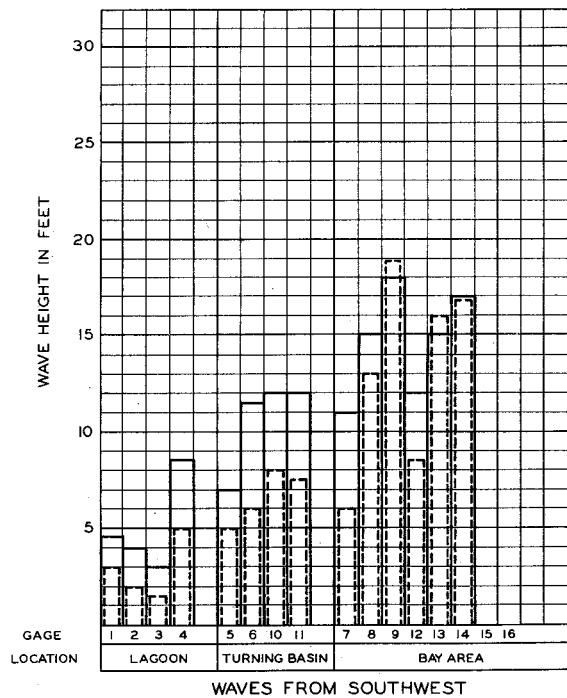
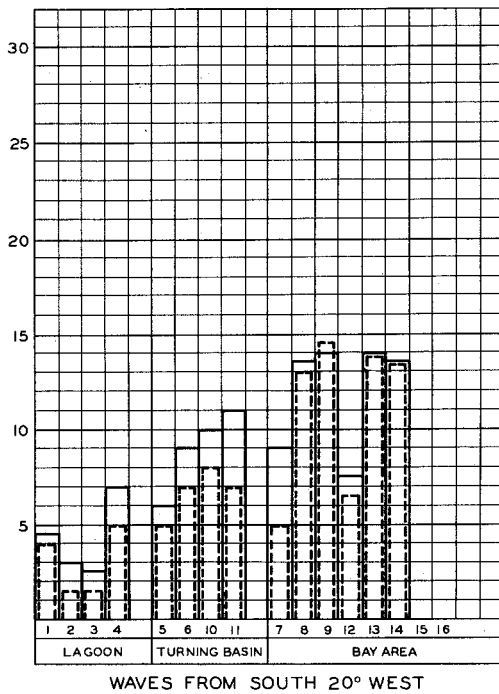
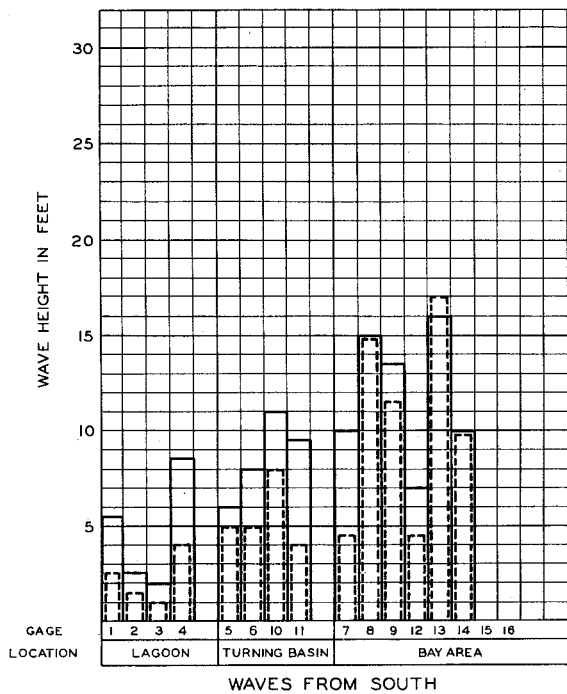
MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN I



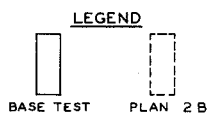
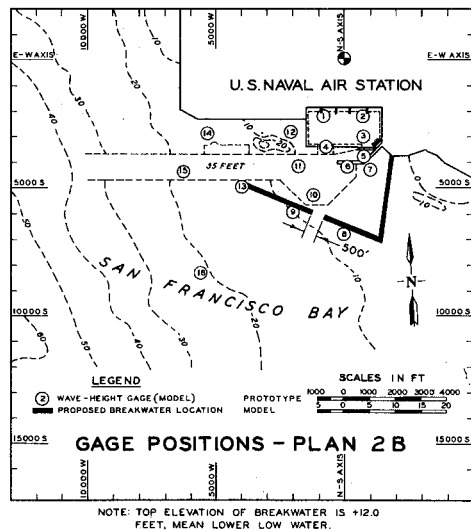
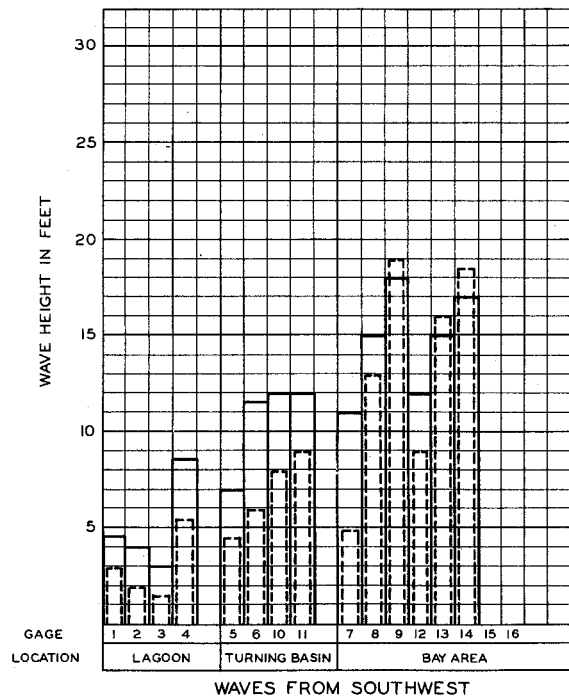
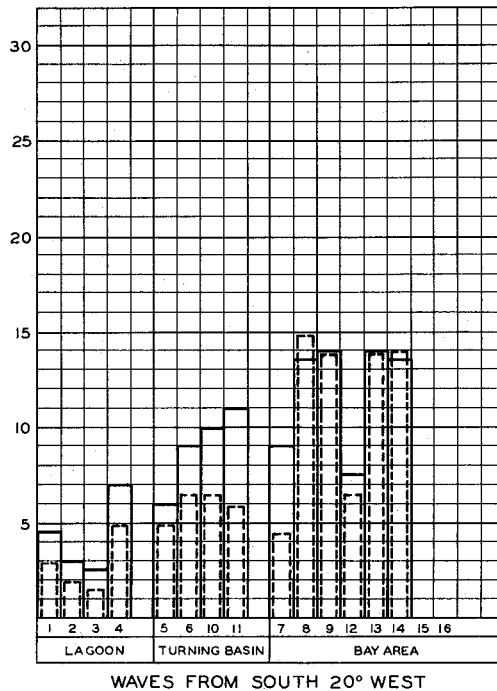
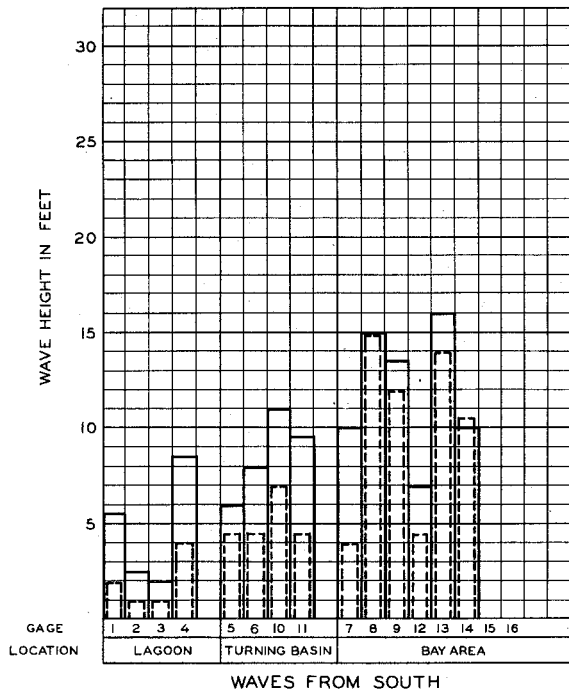
MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN 2



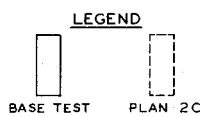
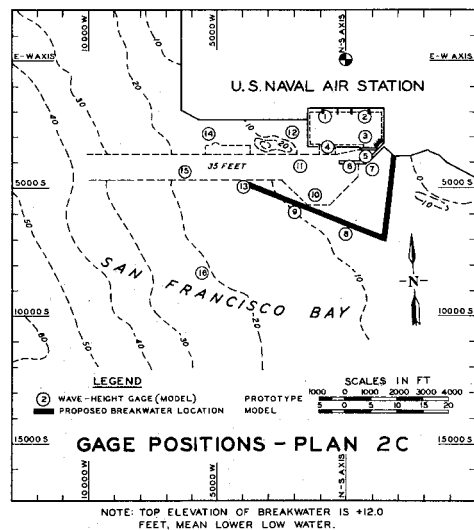
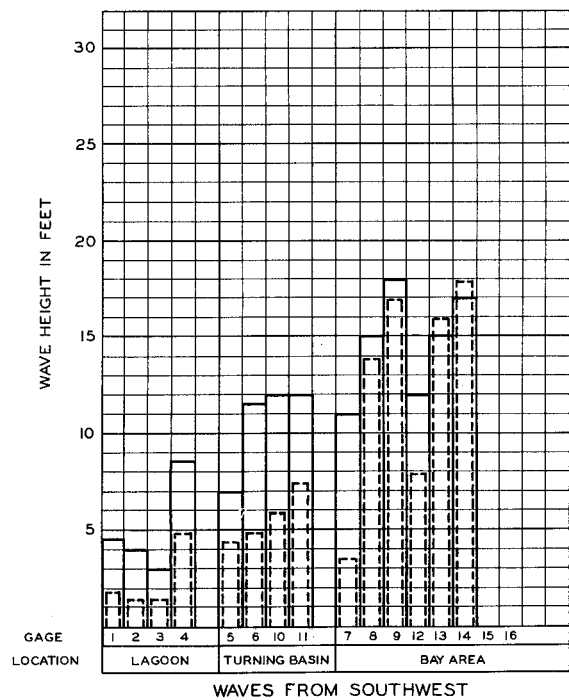
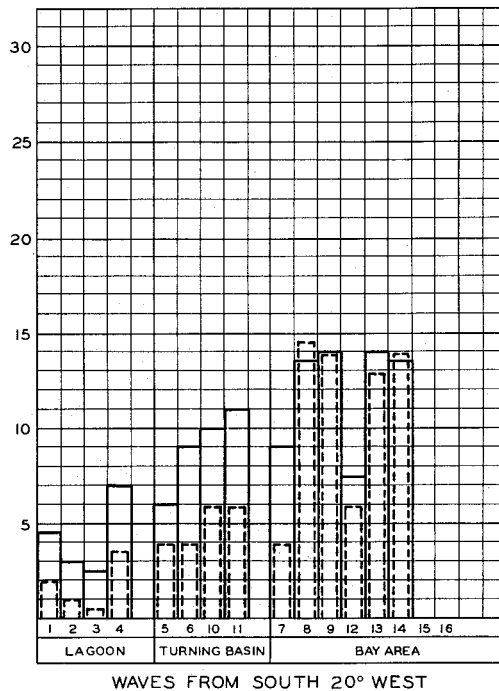
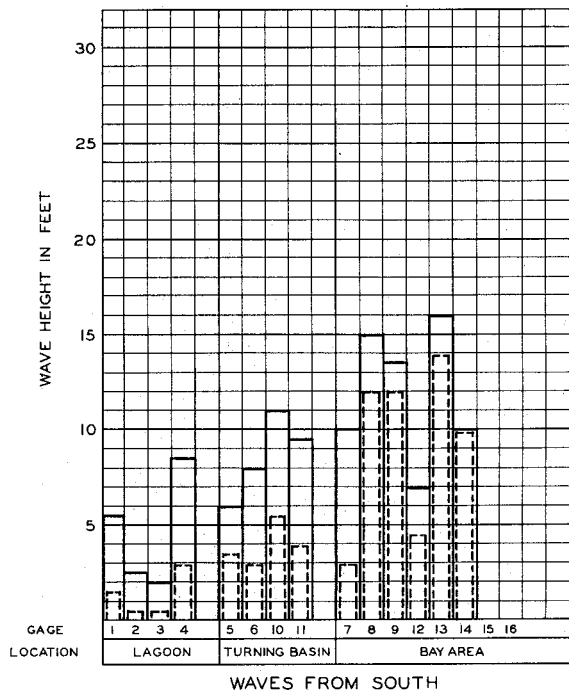
MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN 2A



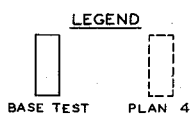
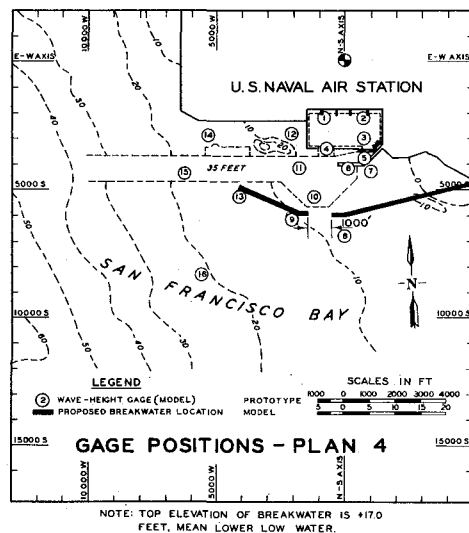
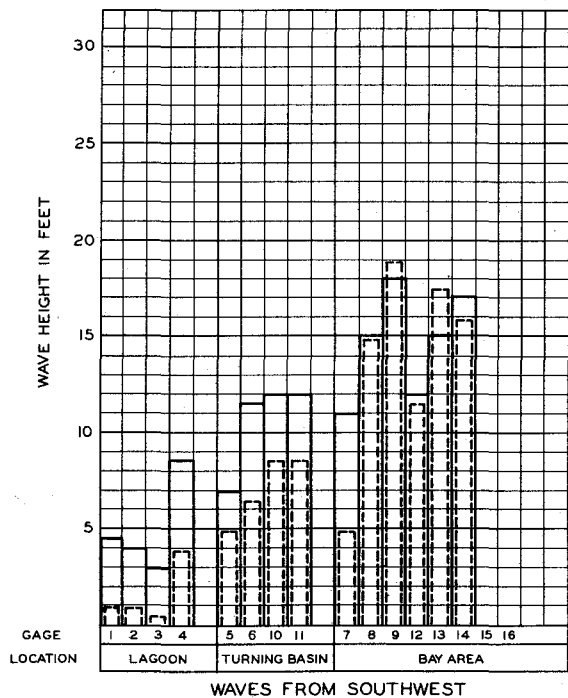
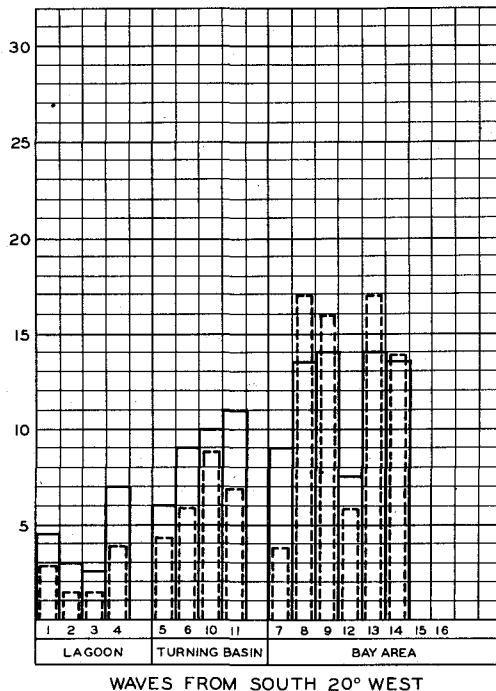
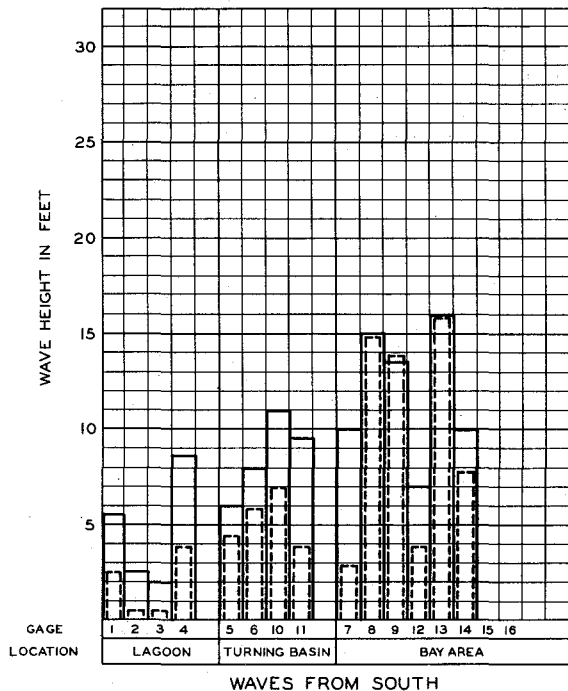
MODEL STUDY OF BREAKWATER LOCATION
U. S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN 2 B



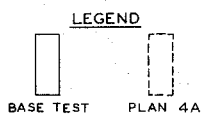
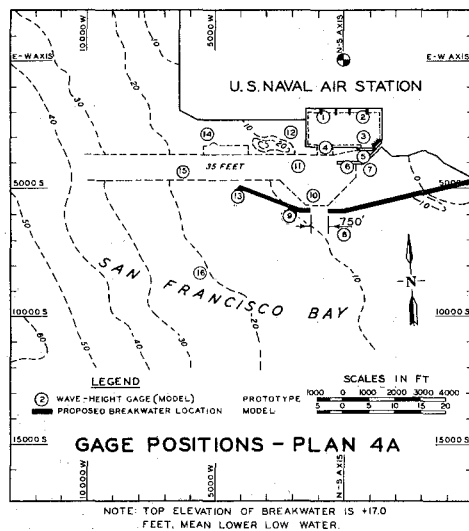
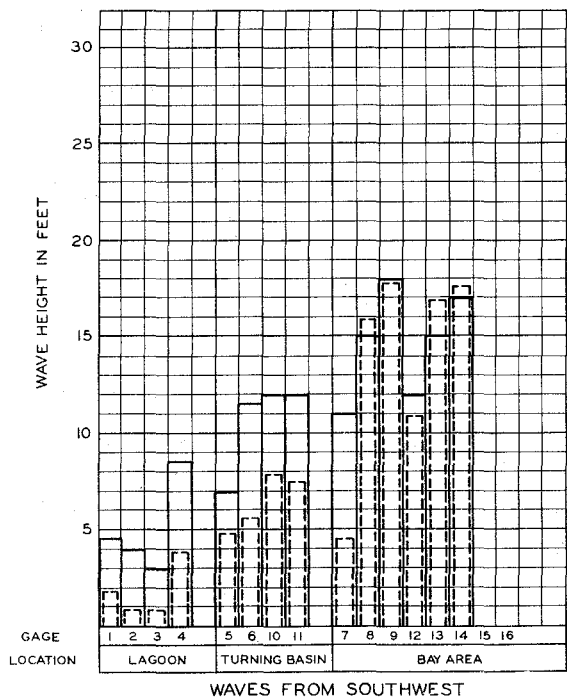
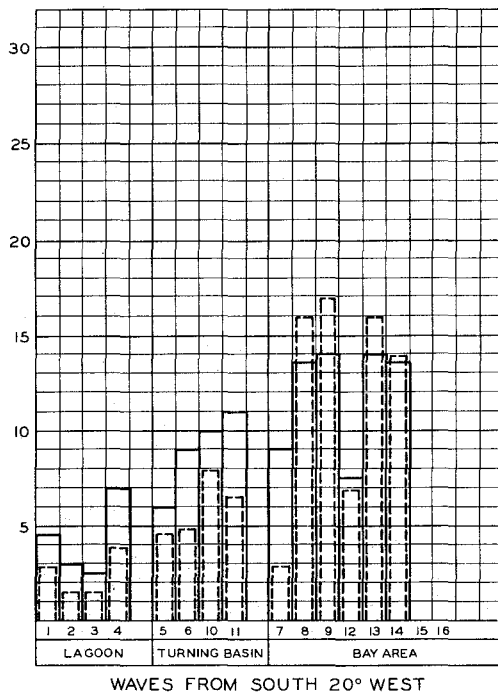
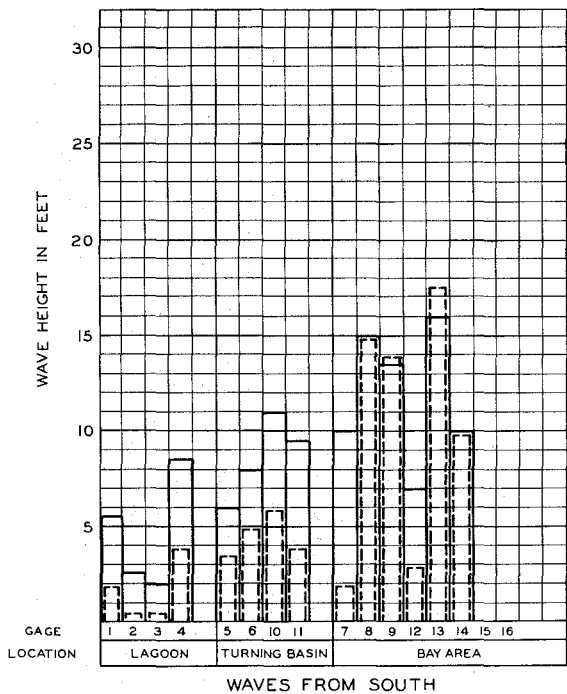
MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN 2C



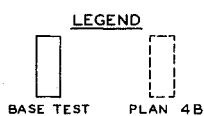
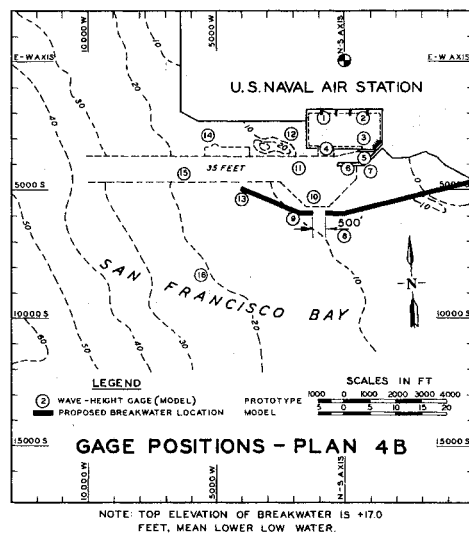
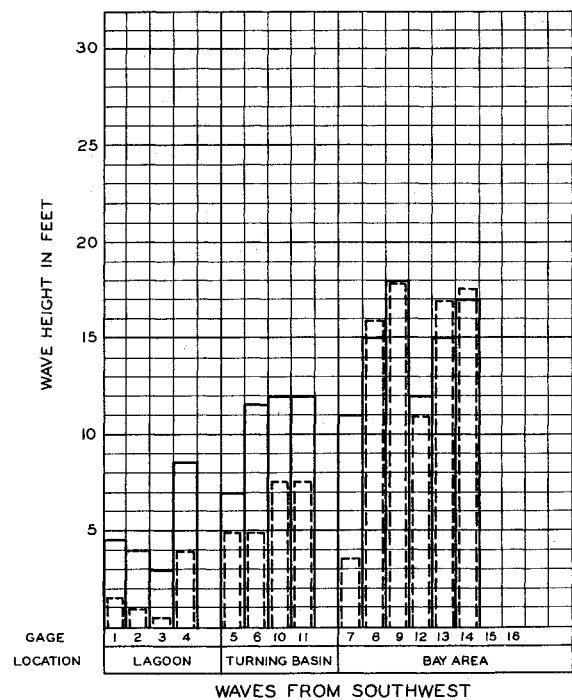
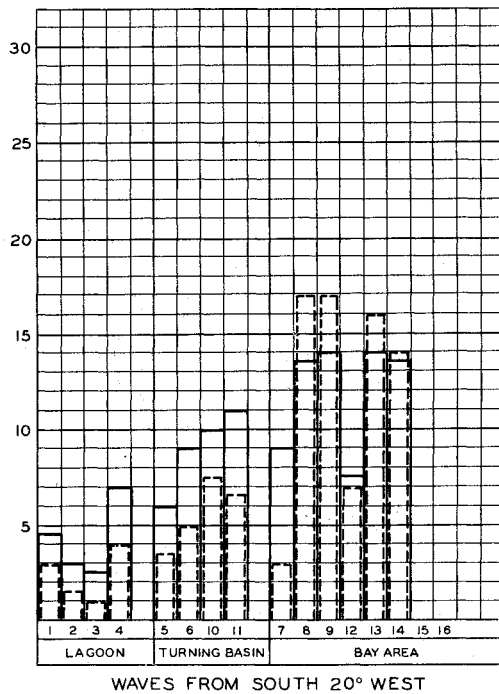
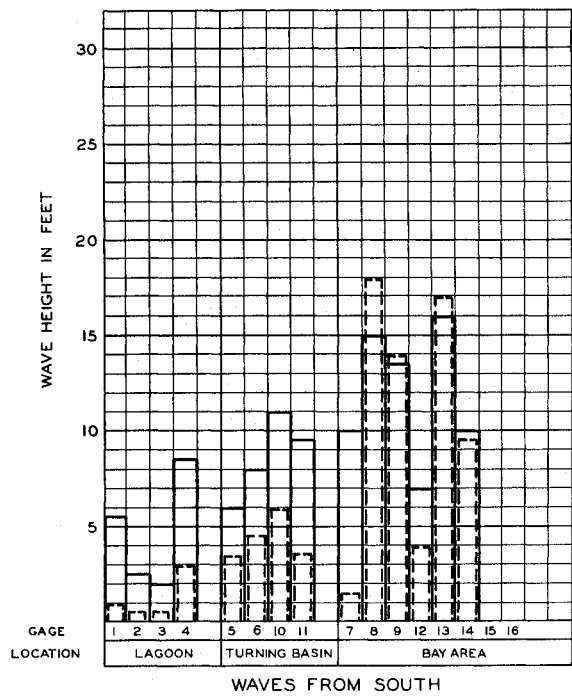
MODEL STUDY OF BREAKWATER LOCATION
U. S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN 4



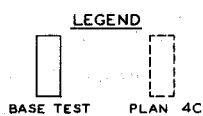
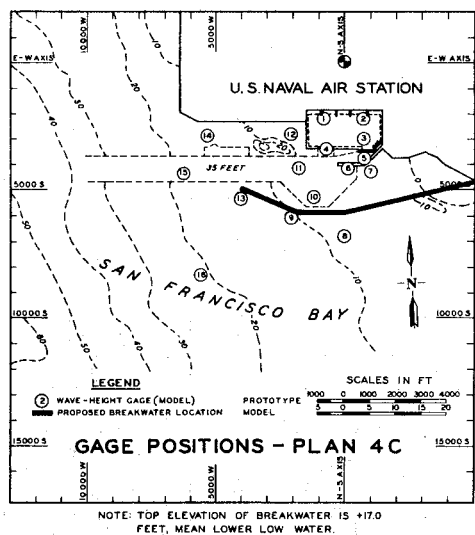
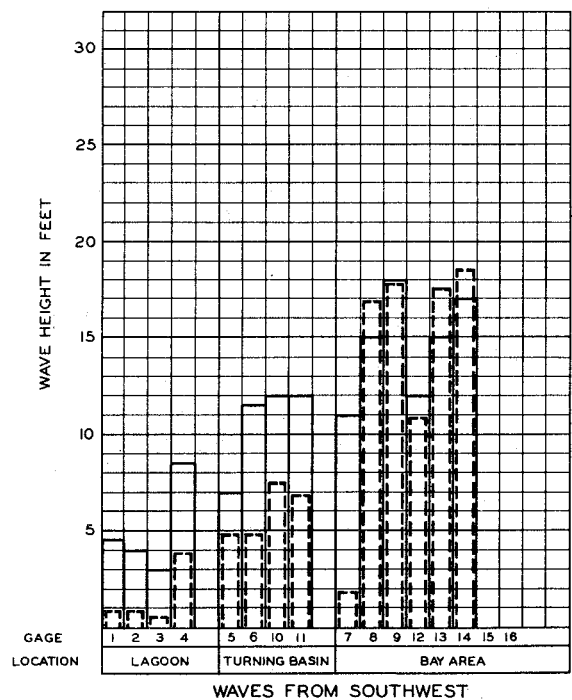
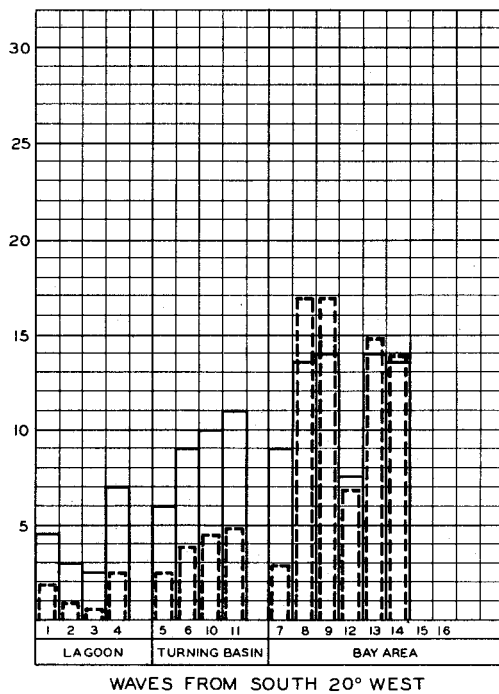
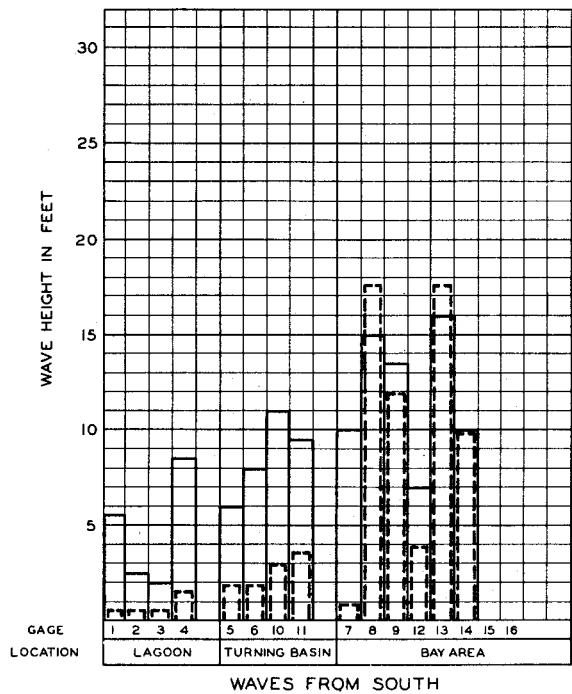
MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN 4A



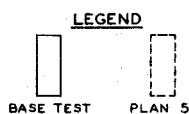
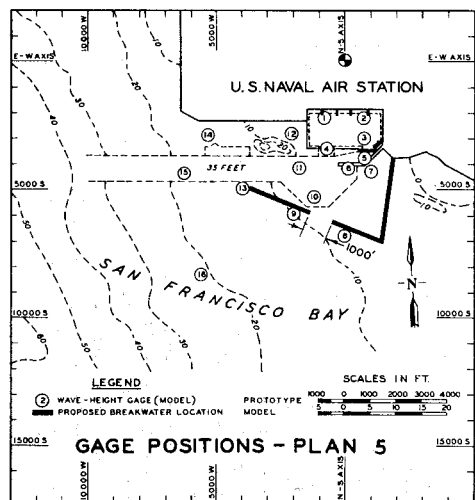
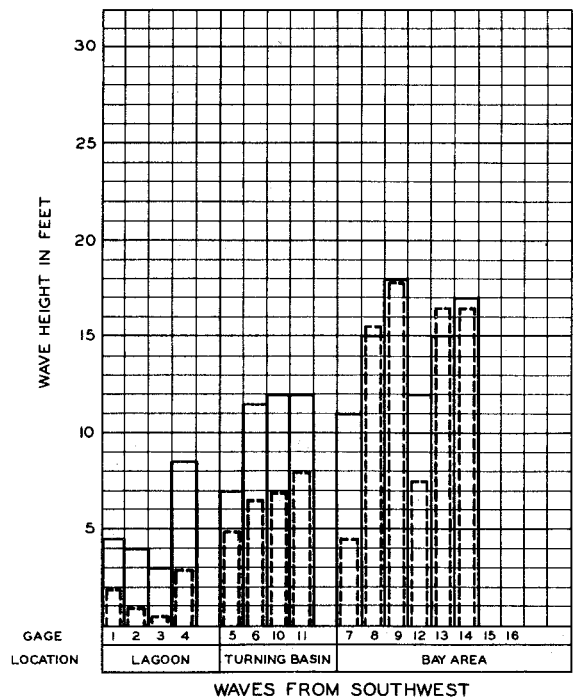
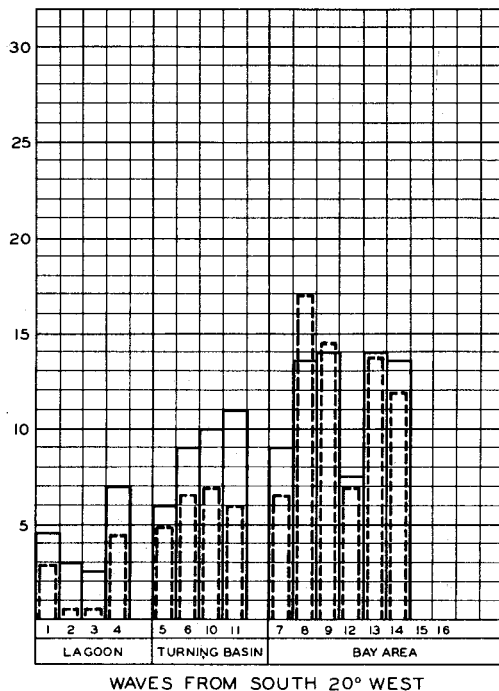
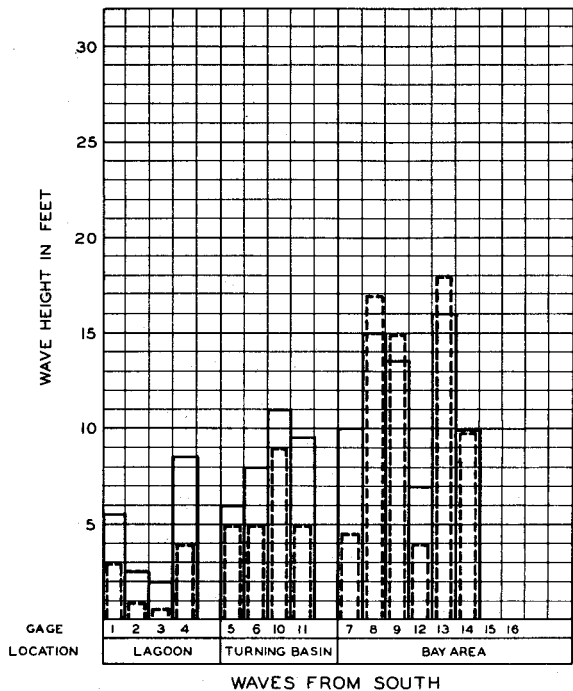
MODEL STUDY OF BREAKWATER LOCATION
U. S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN 4B



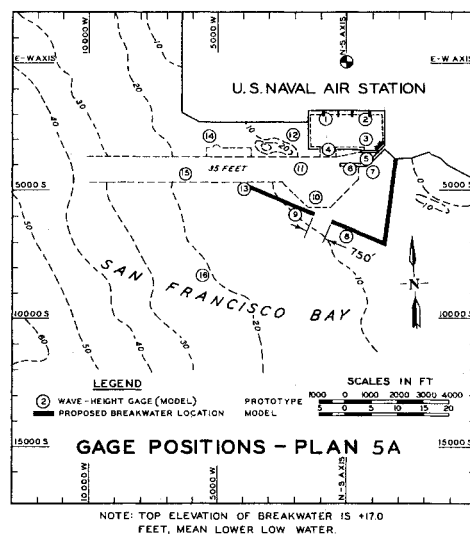
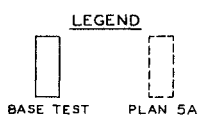
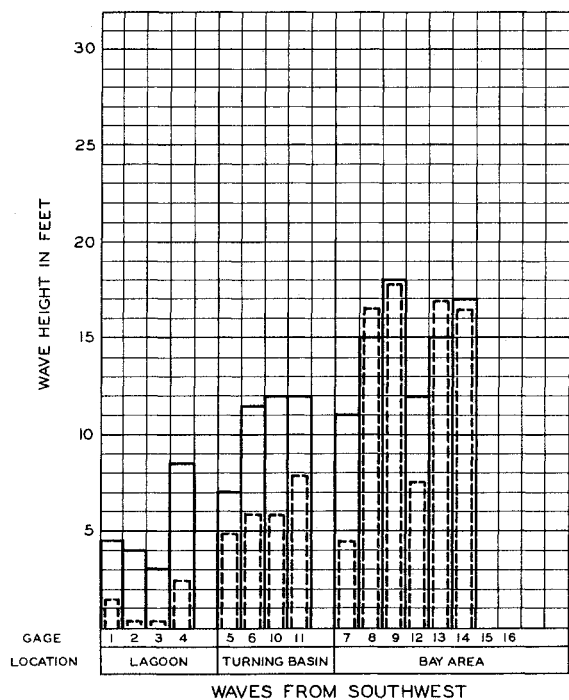
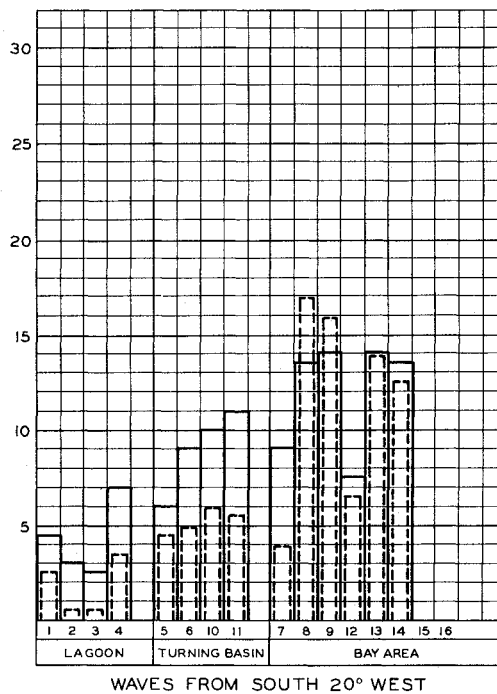
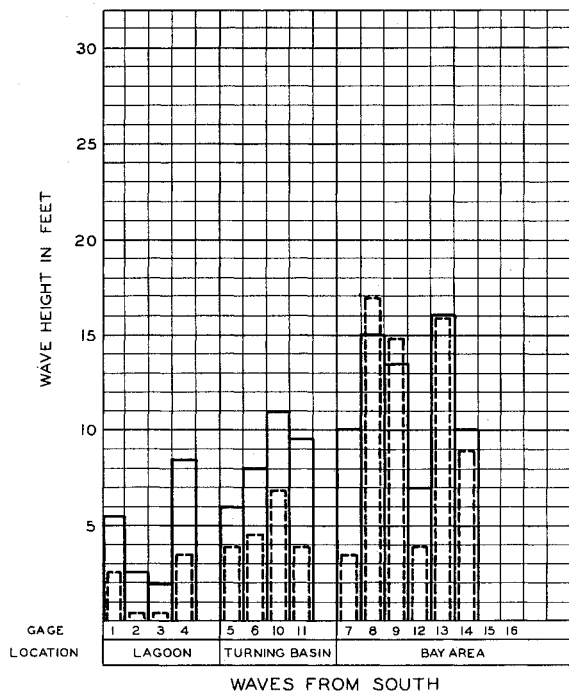
MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN 4C



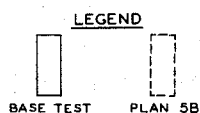
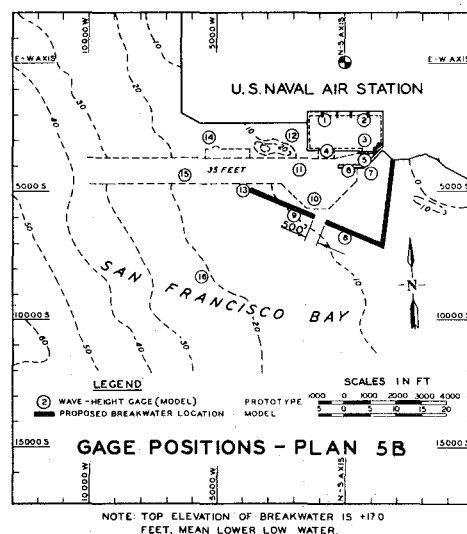
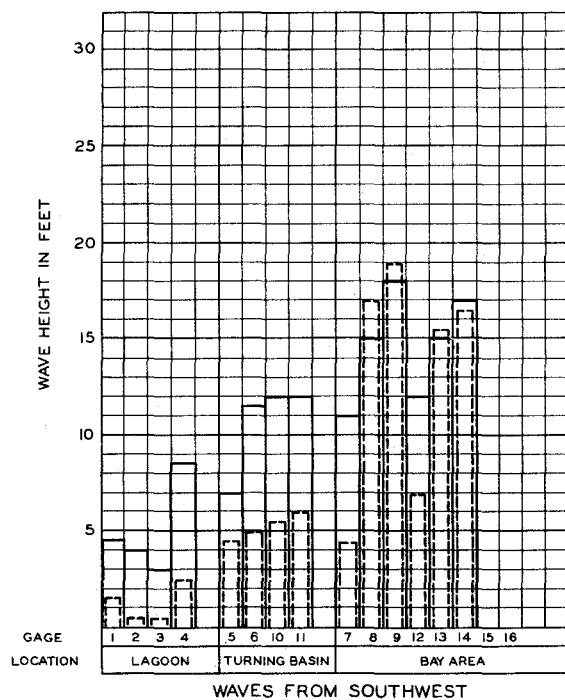
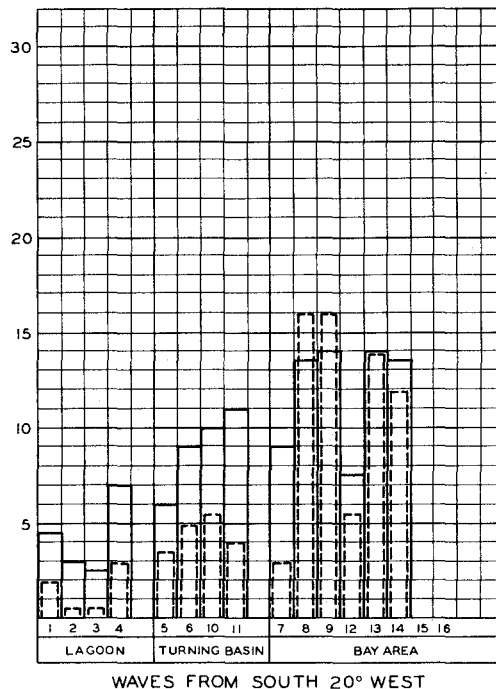
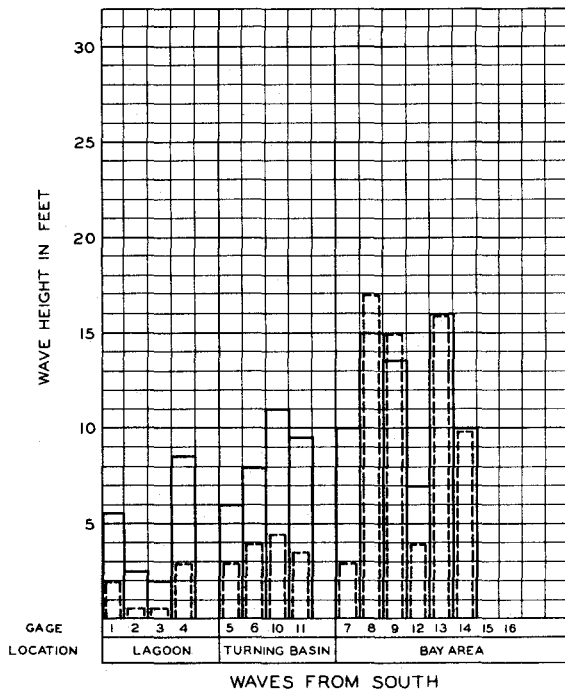
MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN 5



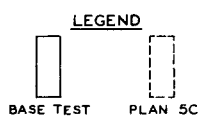
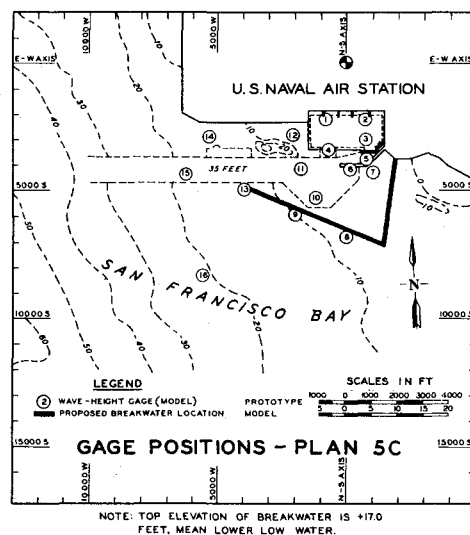
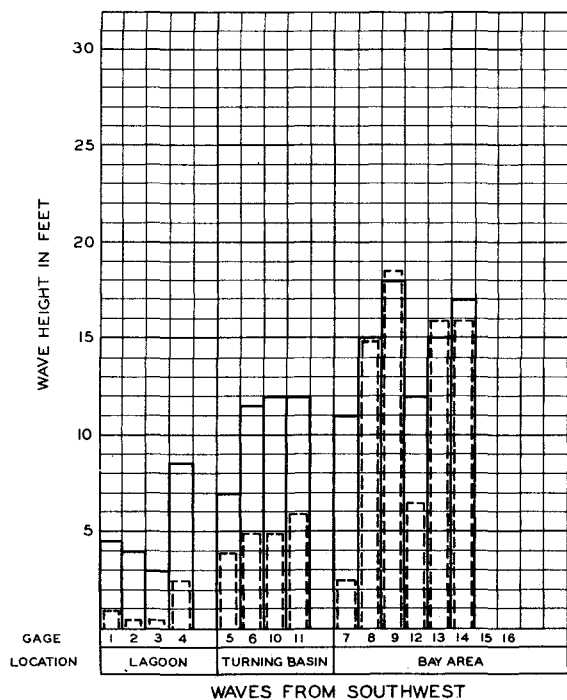
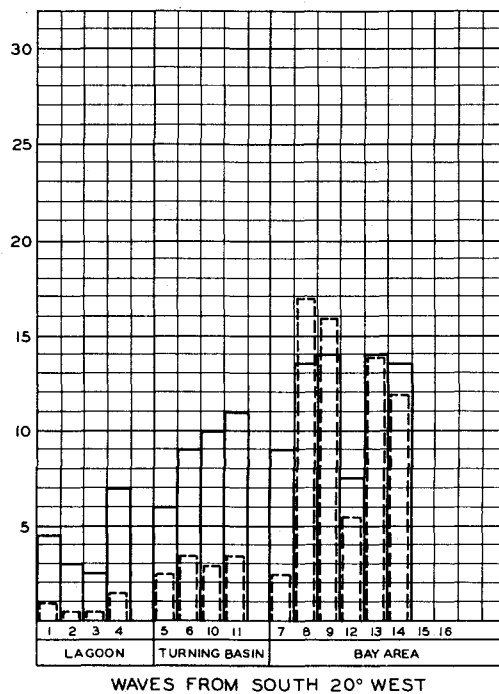
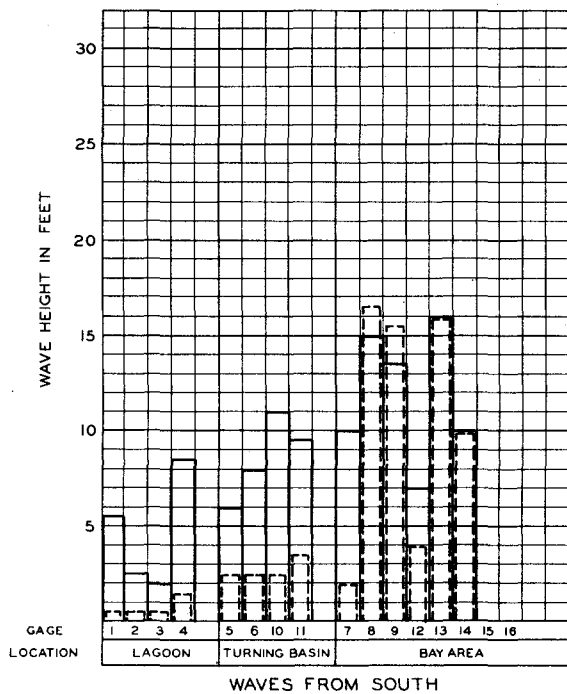
MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN 5A



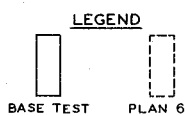
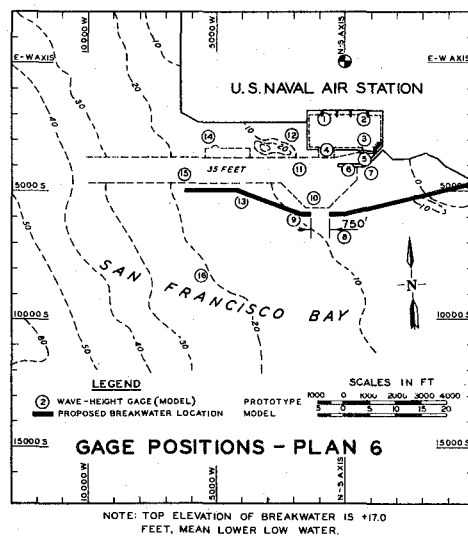
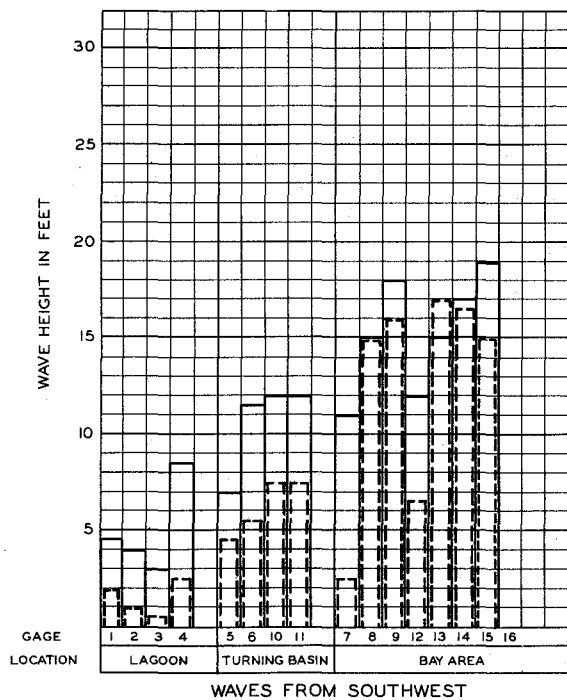
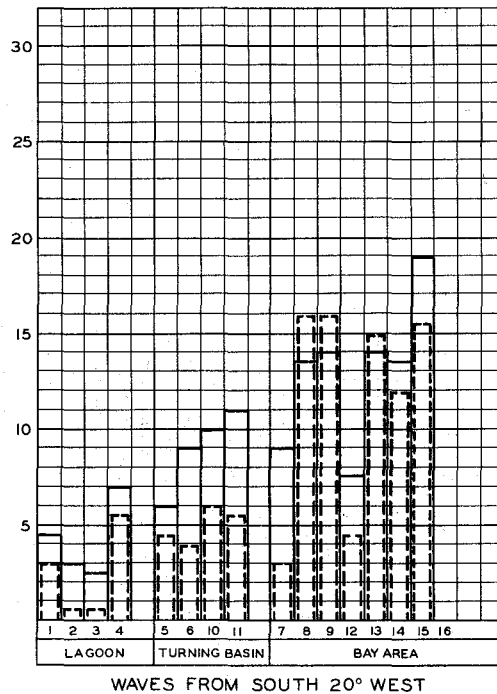
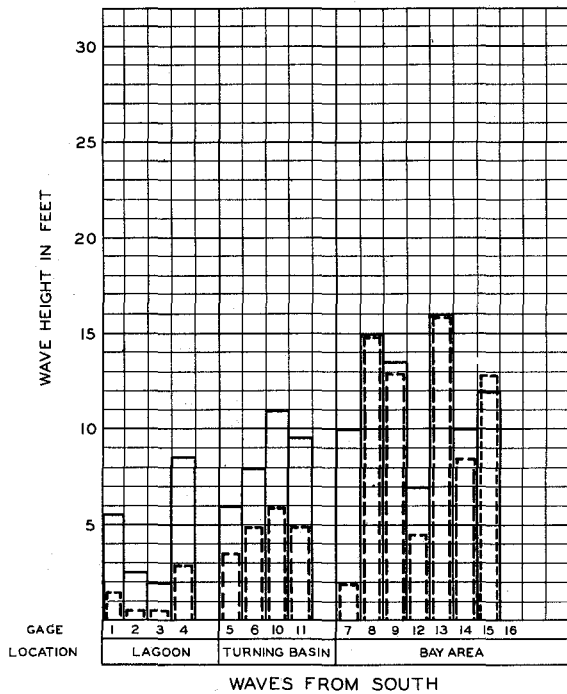
MODEL STUDY OF BREAKWATER LOCATION
U. S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN 5B



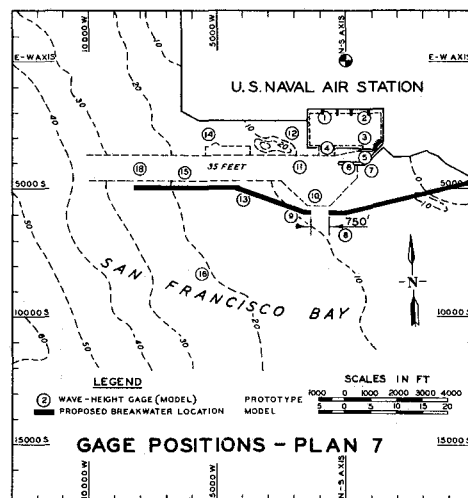
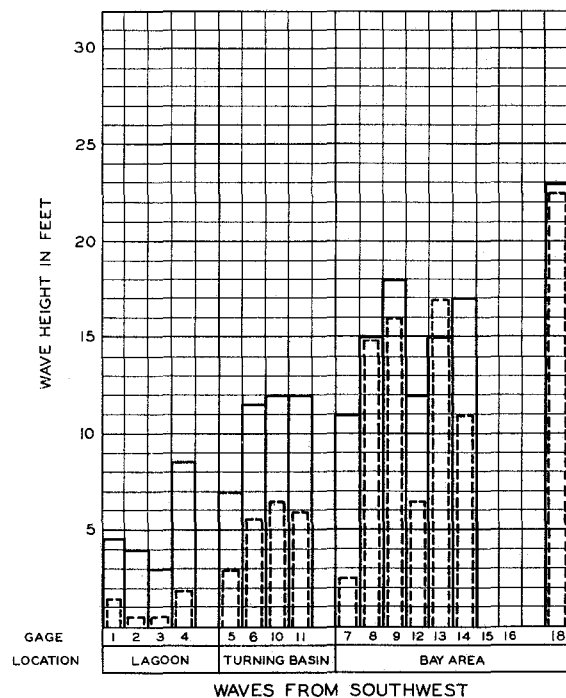
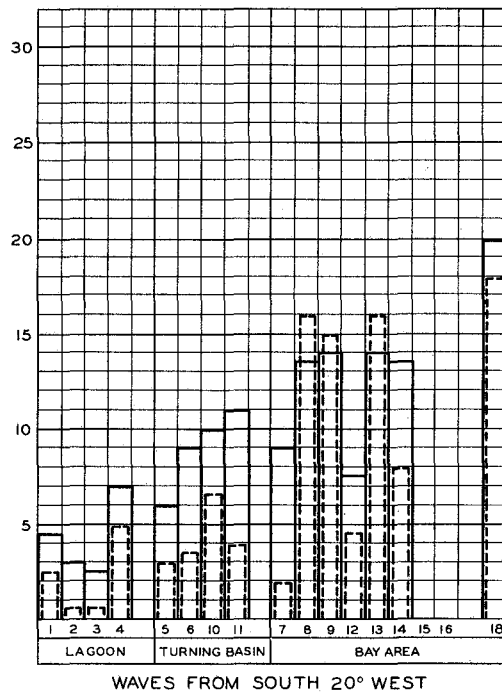
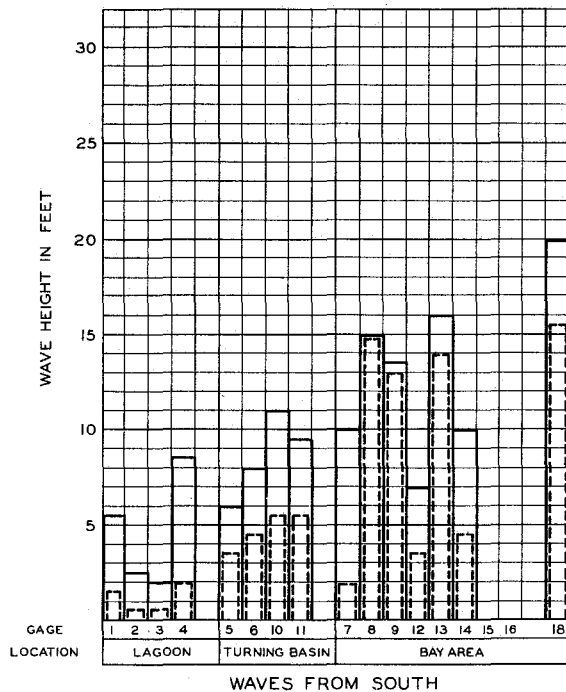
MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN 5C

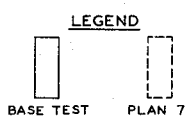


MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN 6

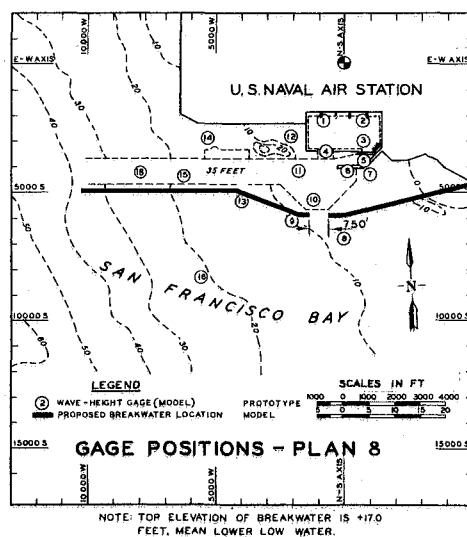
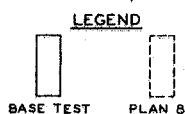
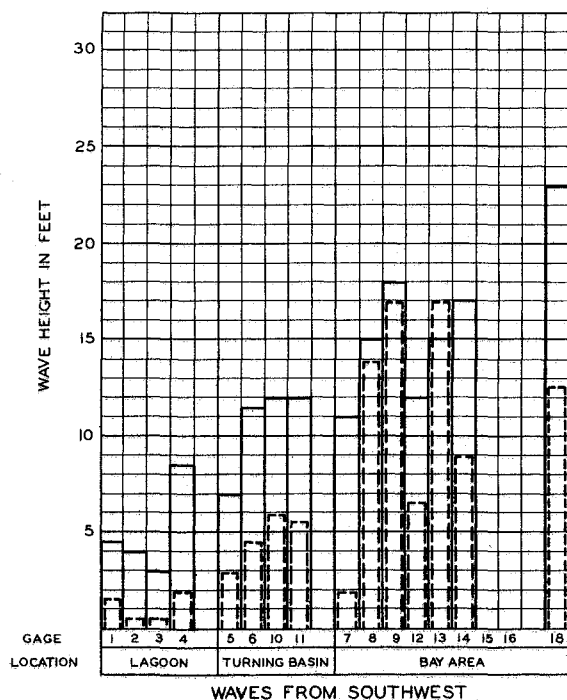
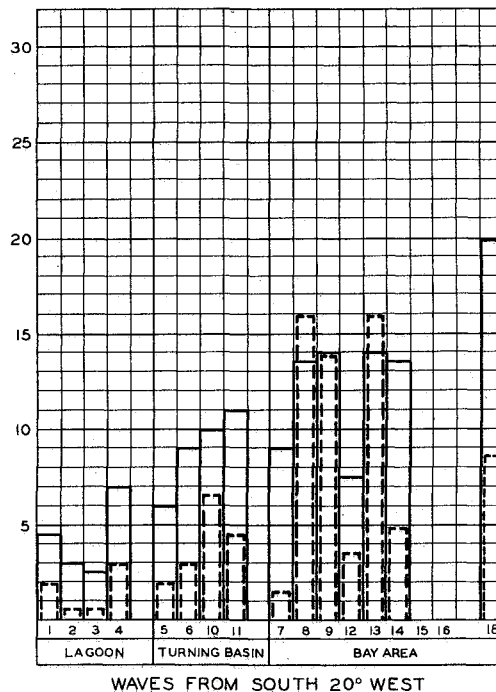
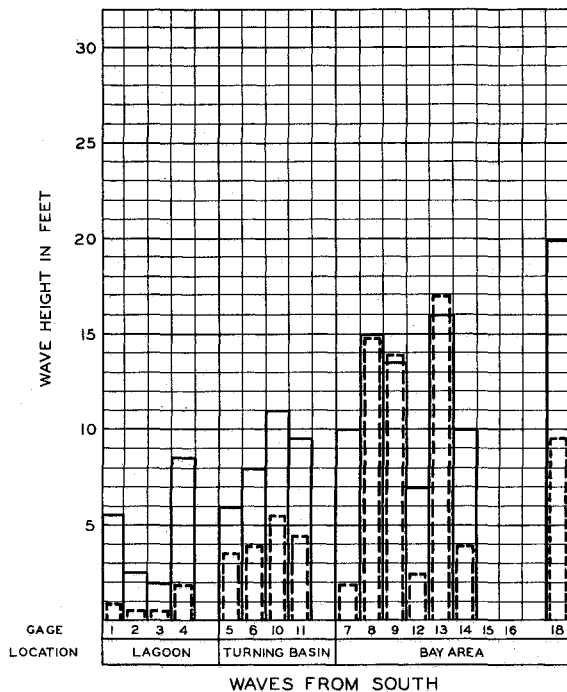


NOTE: TOP ELEVATION OF BREAKWATER IS +17.0 FEET, MEAN LOWER LOW WATER.



MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

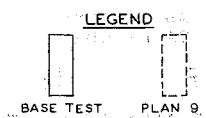
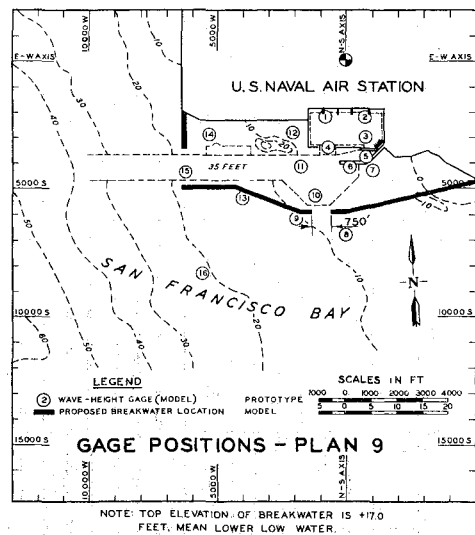
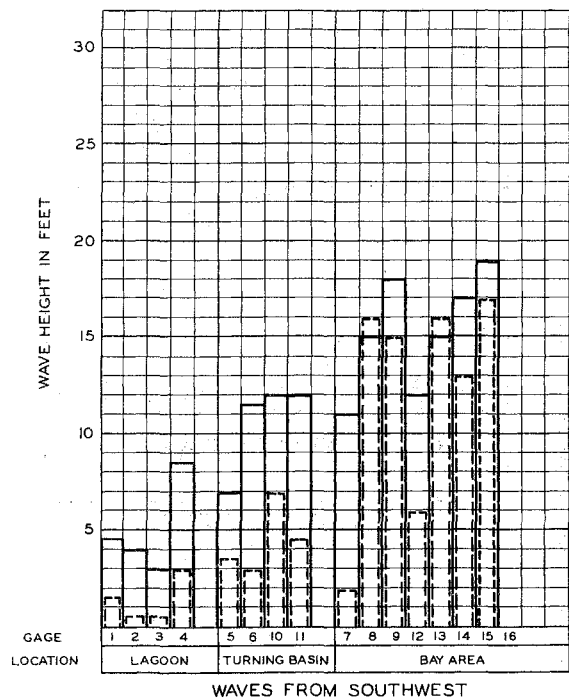
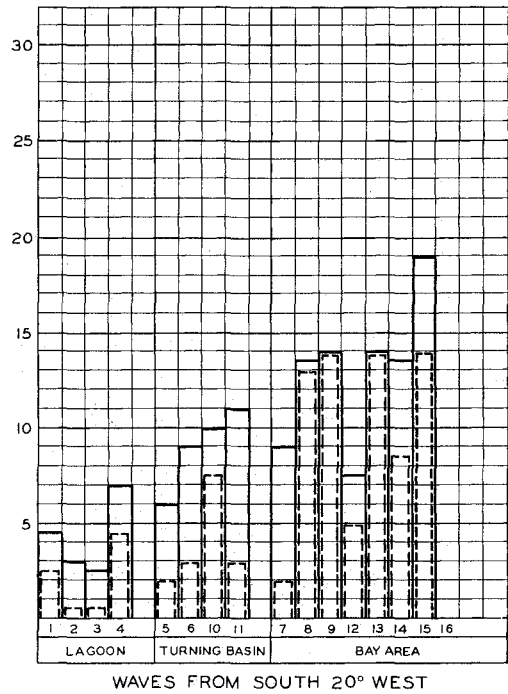
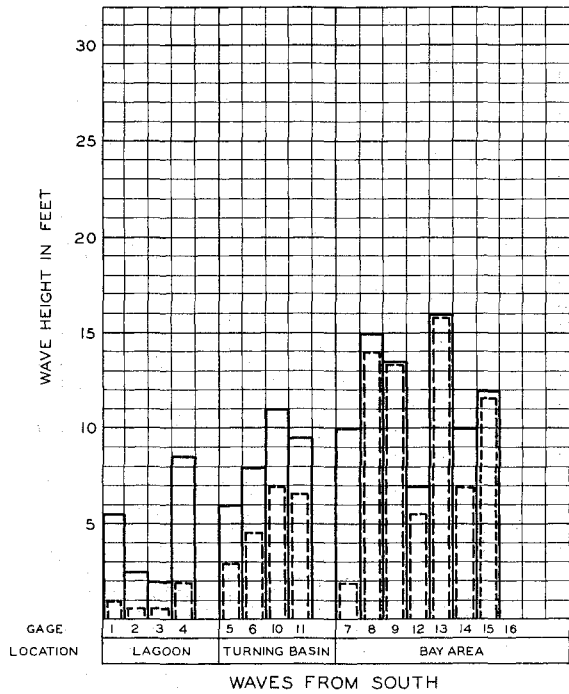
COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN 7



MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

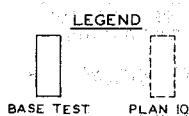
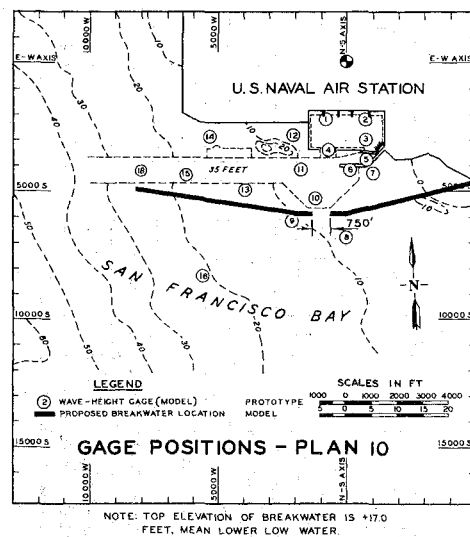
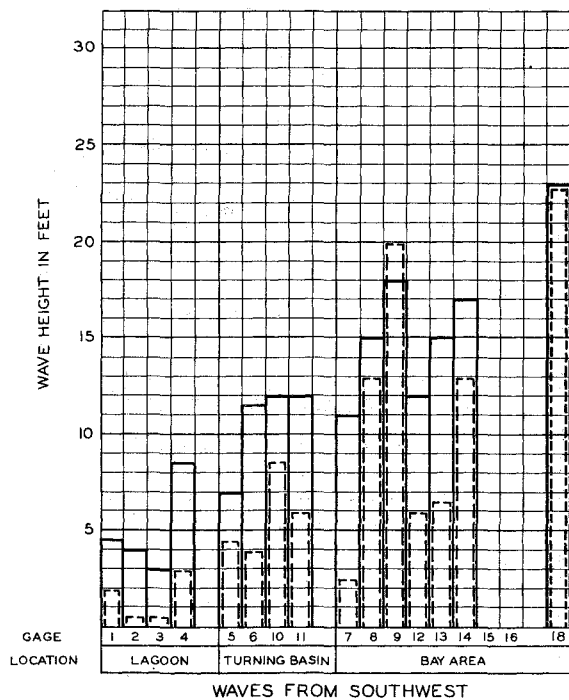
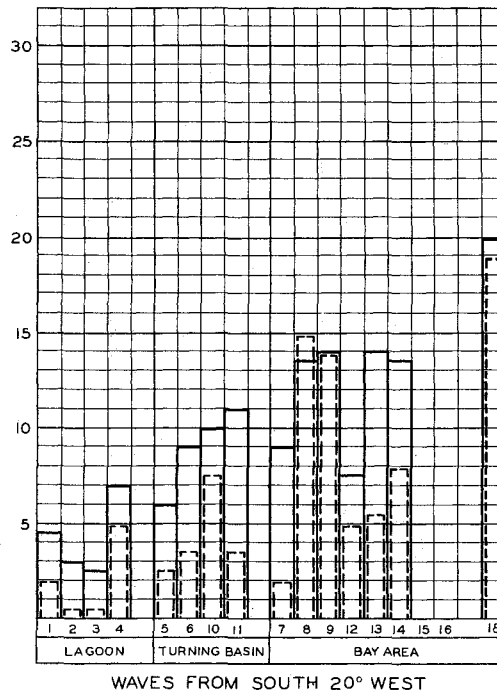
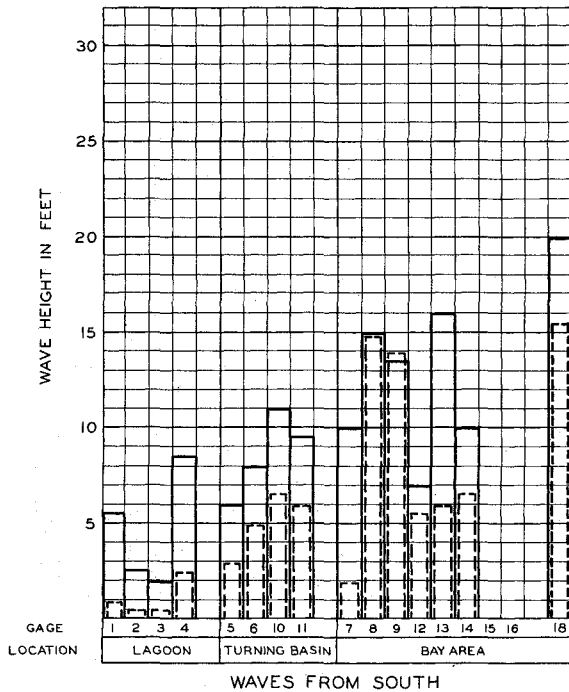
COMPARISON OF WAVE HEIGHTS

BASE TEST AND PLAN 8



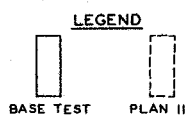
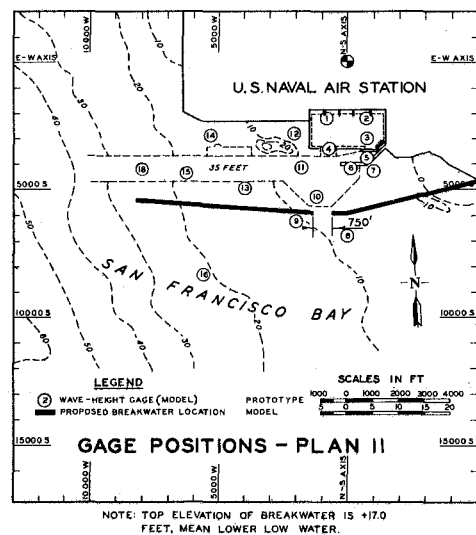
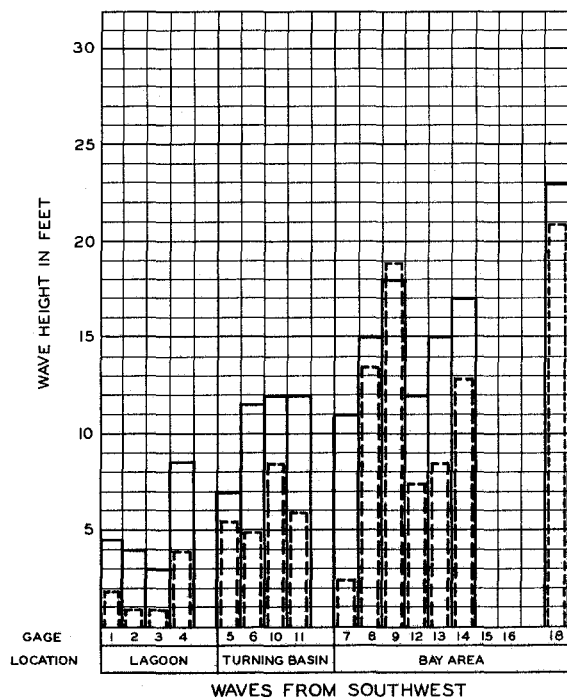
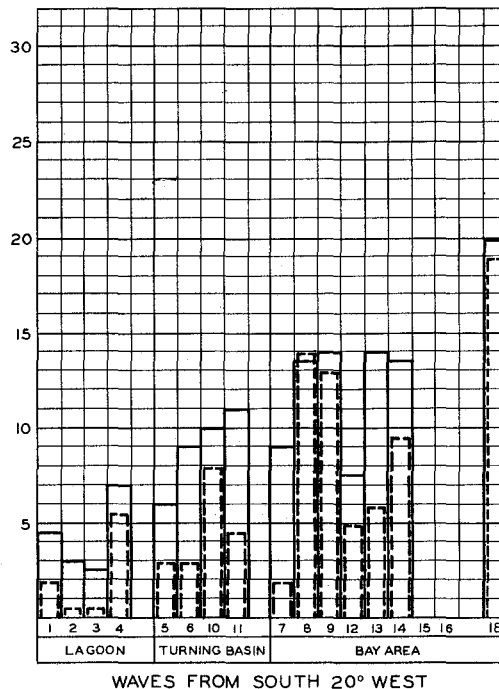
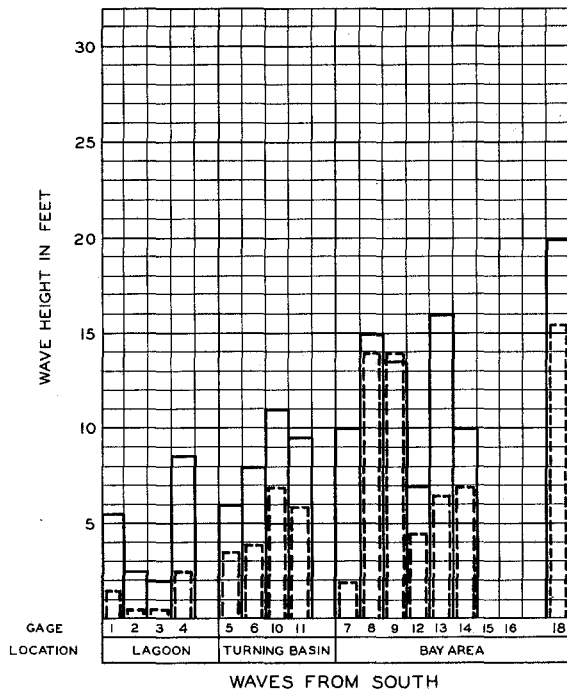
MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN 9



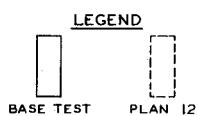
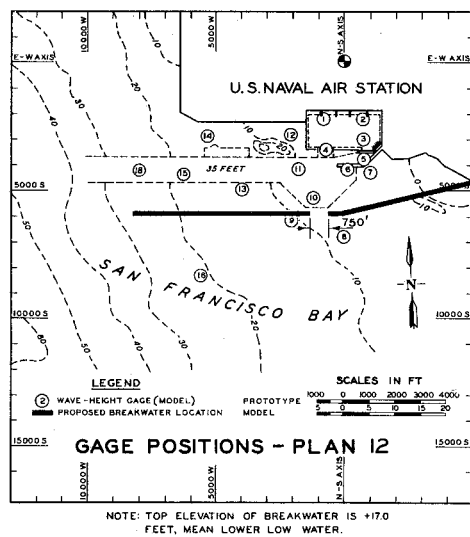
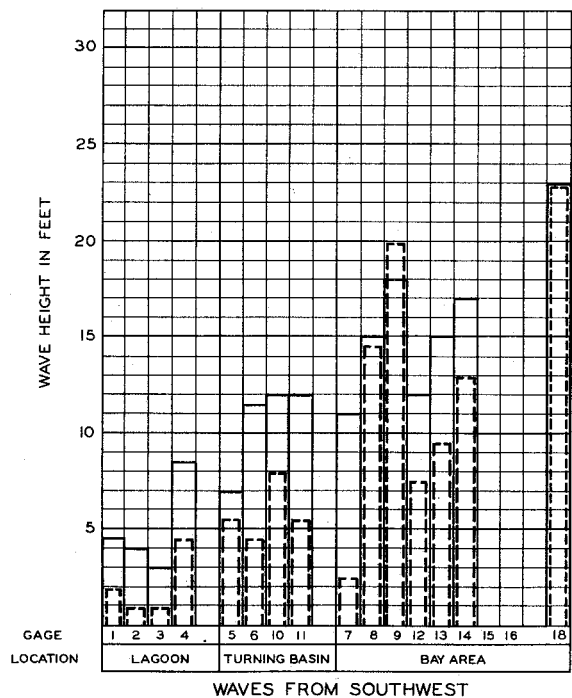
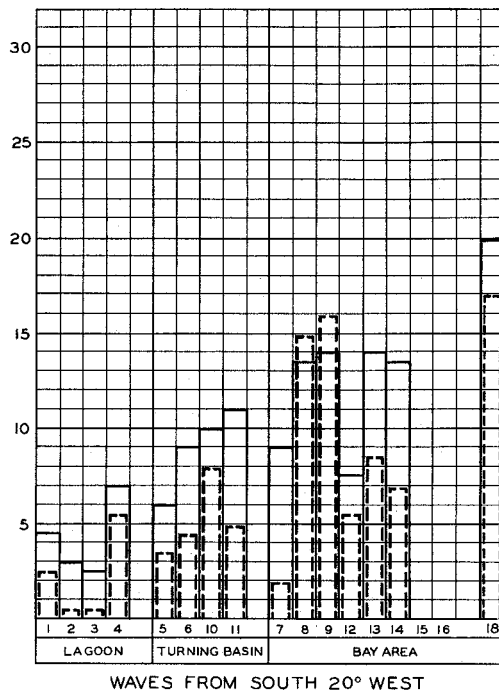
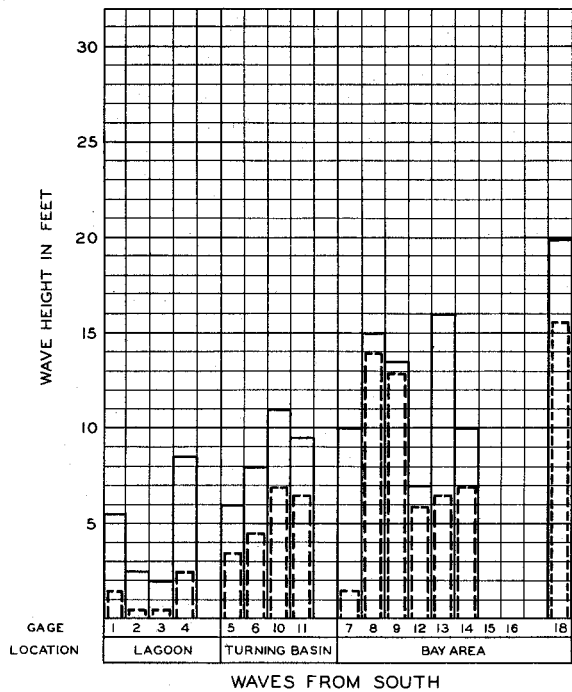
MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN 10



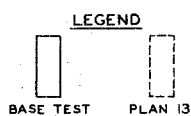
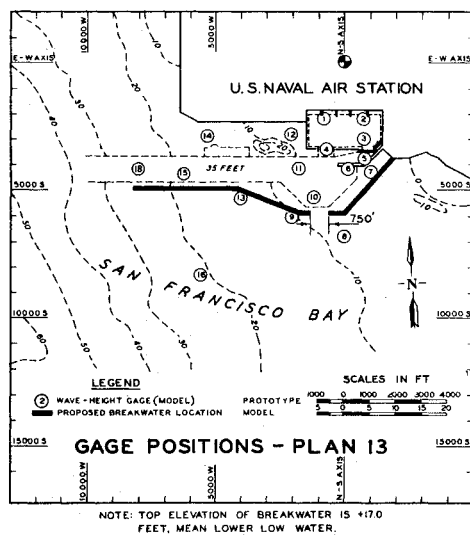
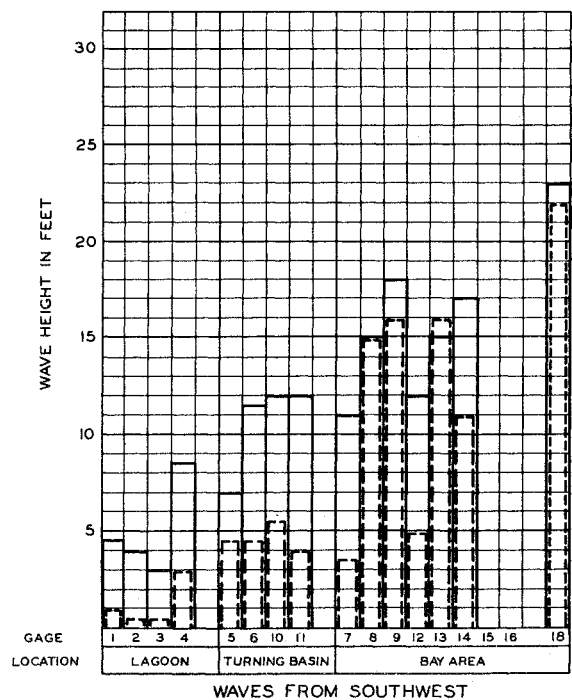
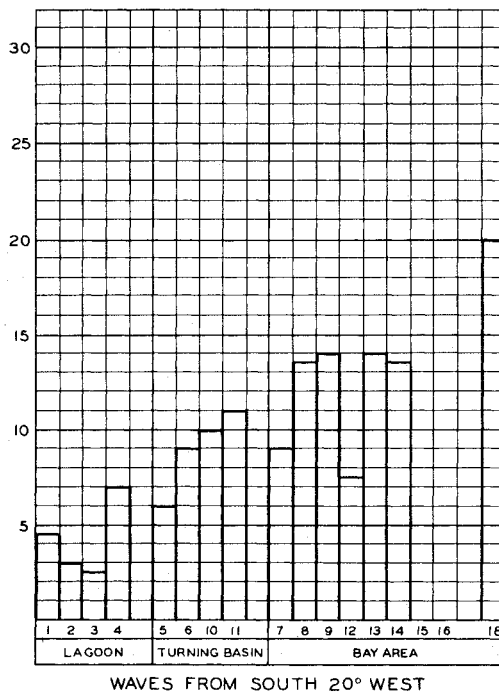
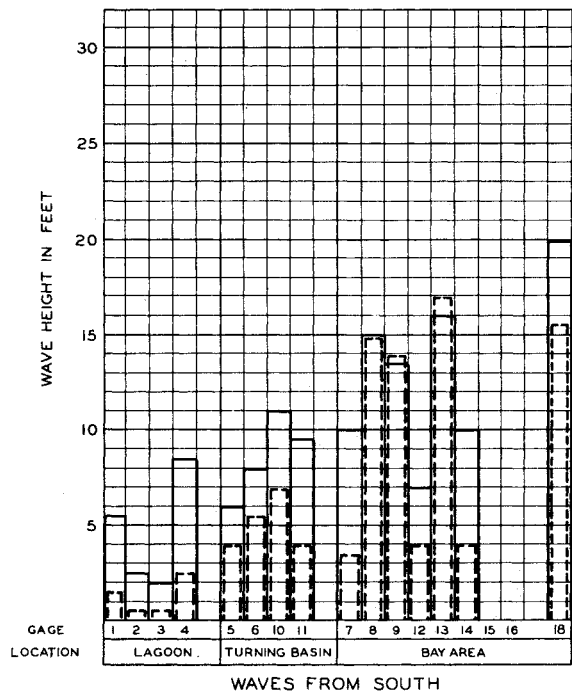
MODEL STUDY OF BREAKWATER LOCATION
U. S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN II



MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

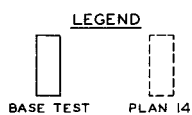
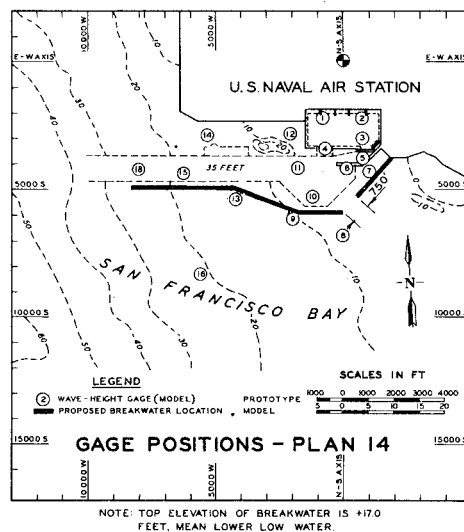
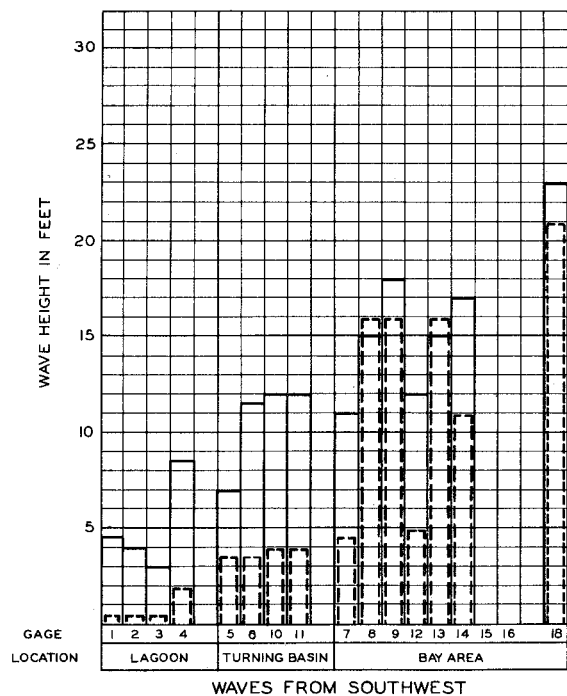
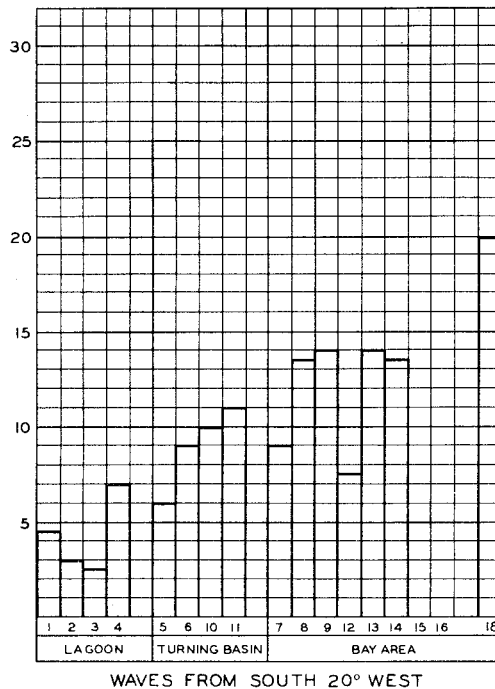
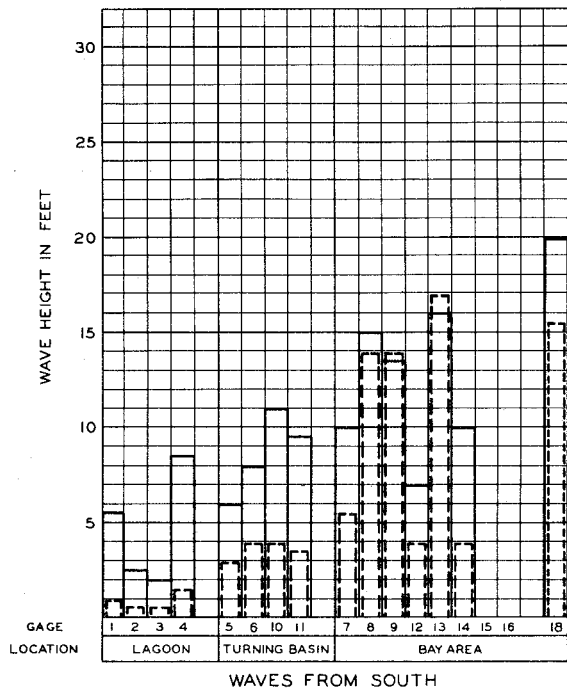
COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN 12



MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

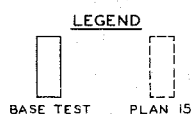
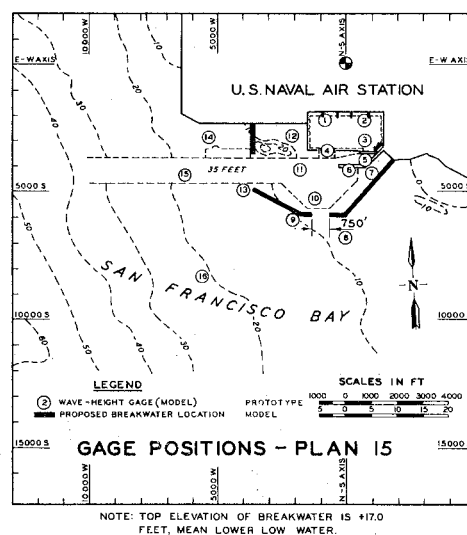
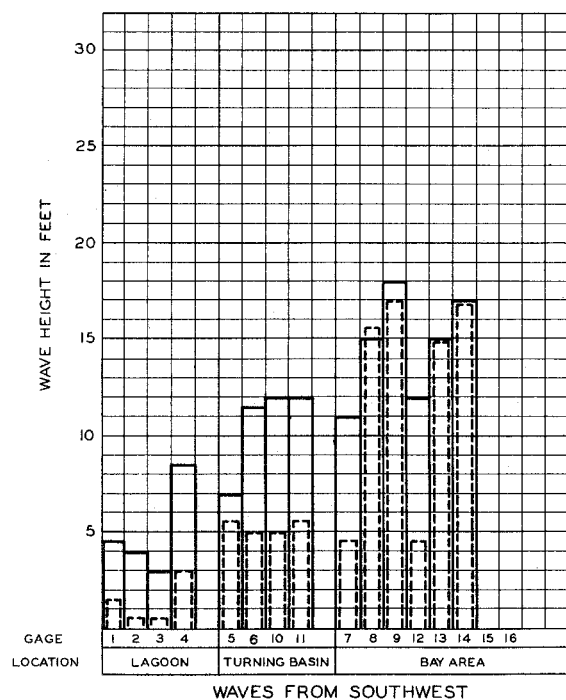
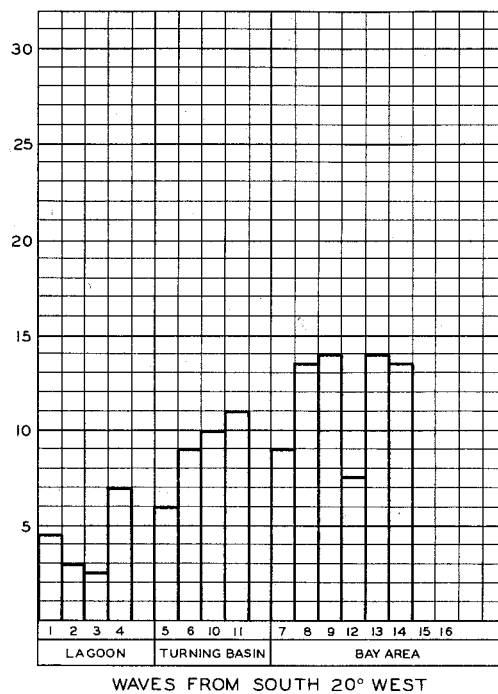
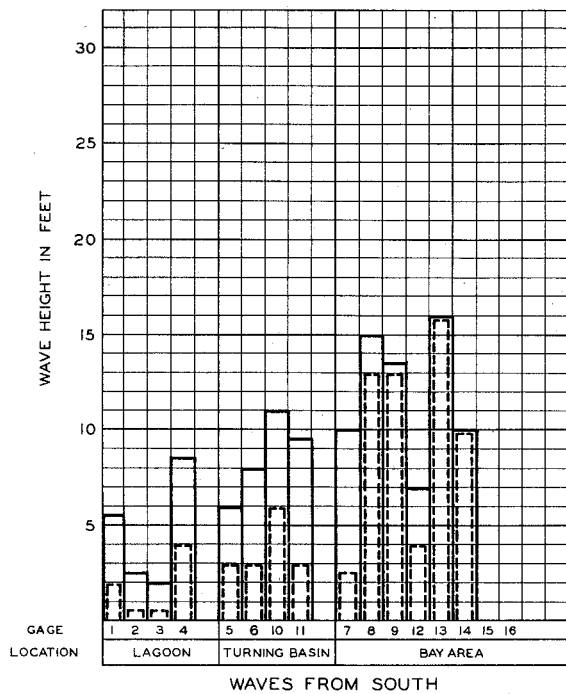
COMPARISON OF WAVE HEIGHTS

BASE TEST AND PLAN 13



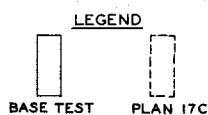
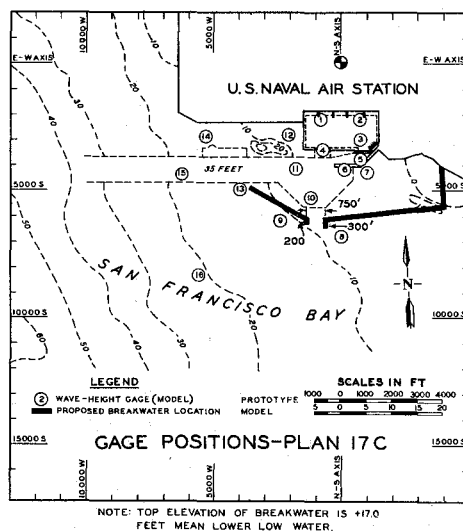
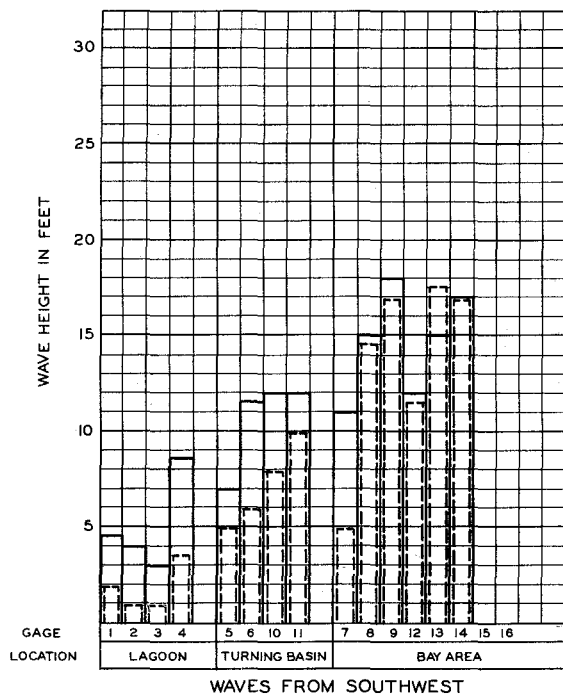
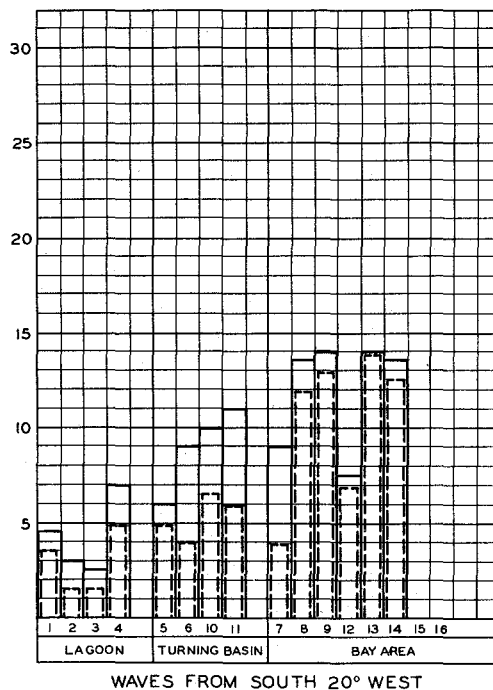
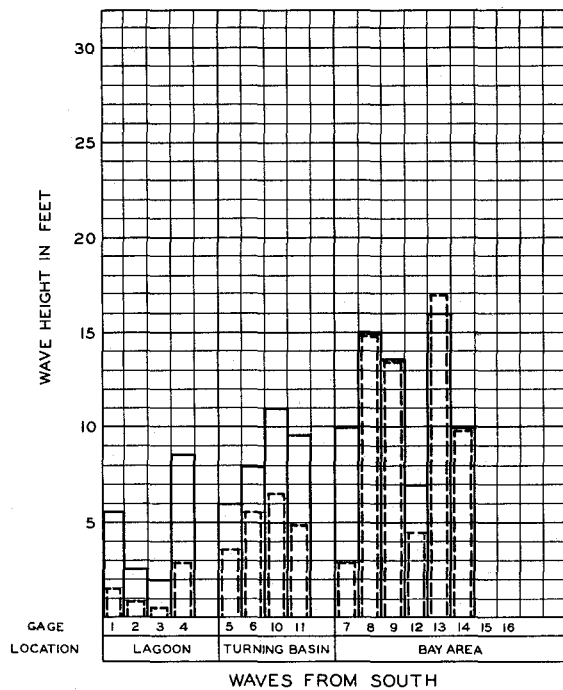
MODEL STUDY OF BREAKWATER LOCATION
U. S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN 14



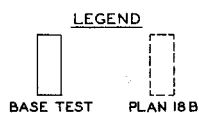
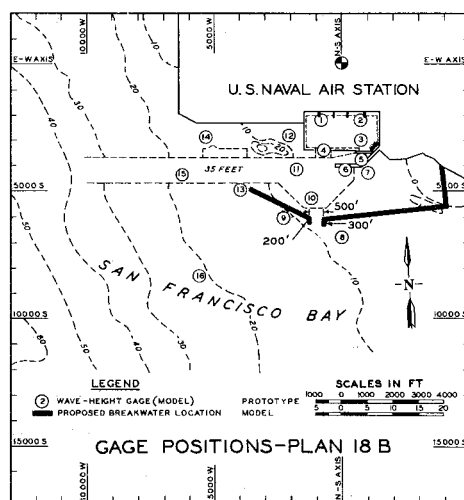
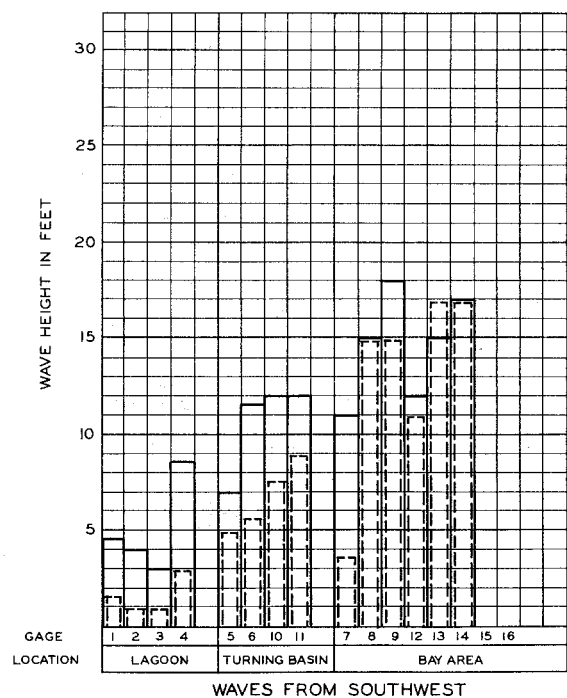
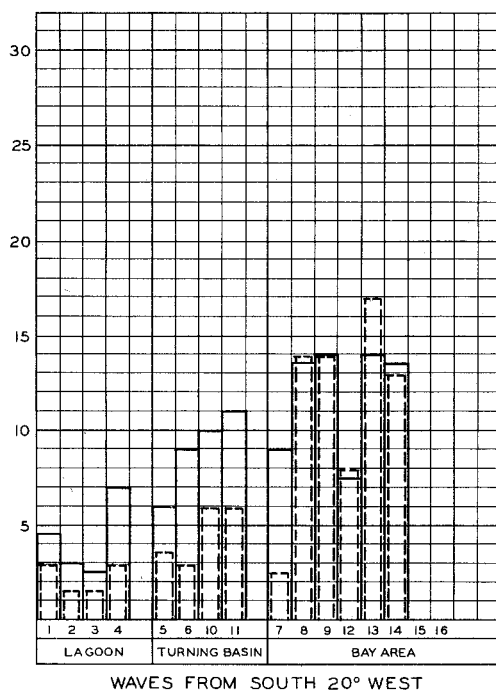
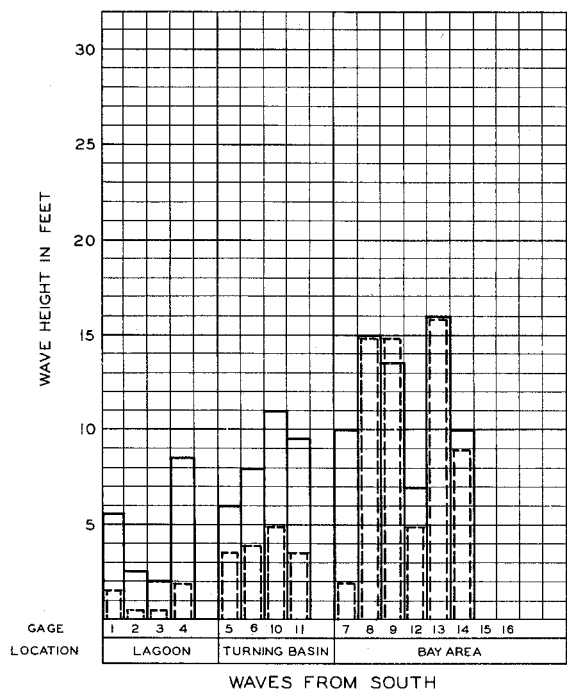
MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN 15



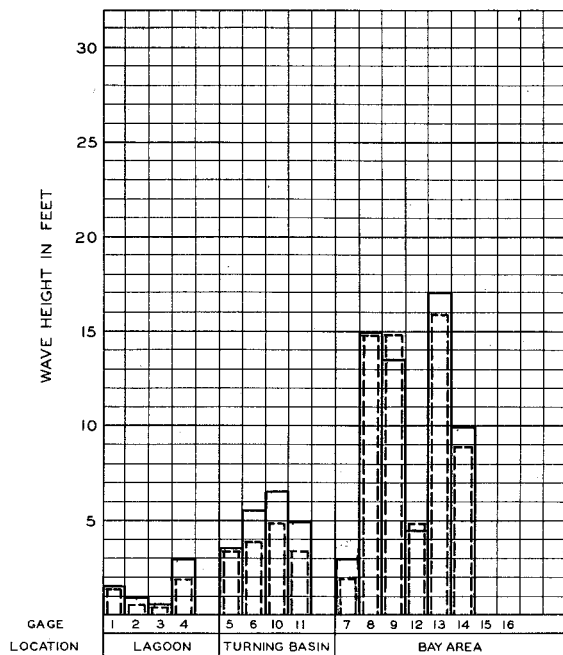
MODEL STUDY OF BREAKWATER LOCATION
U. S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN 17C

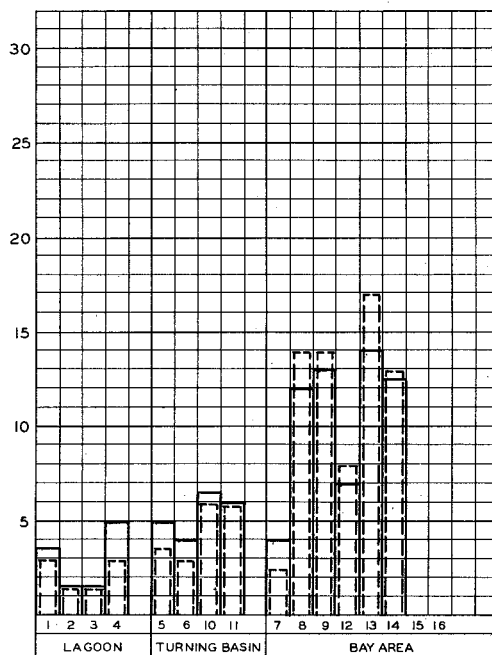


MODEL STUDY OF BREAKWATER LOCATION
U. S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

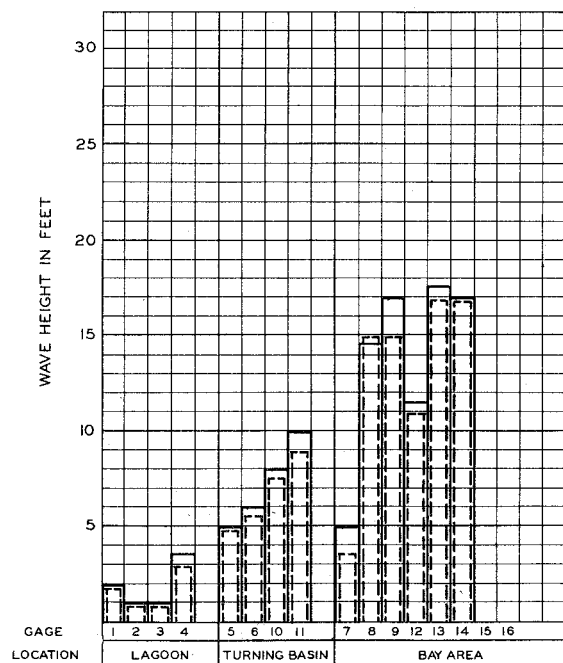
COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN 18B



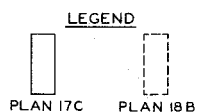
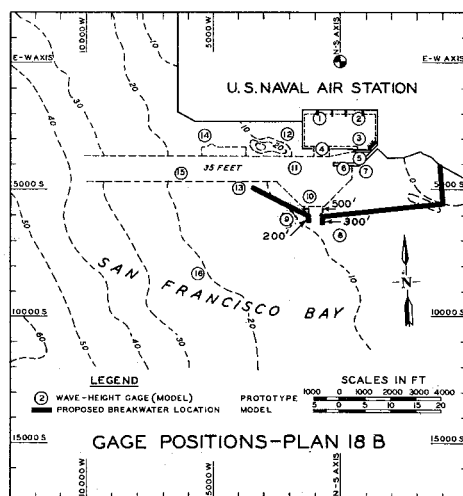
WAVES FROM SOUTH



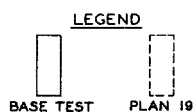
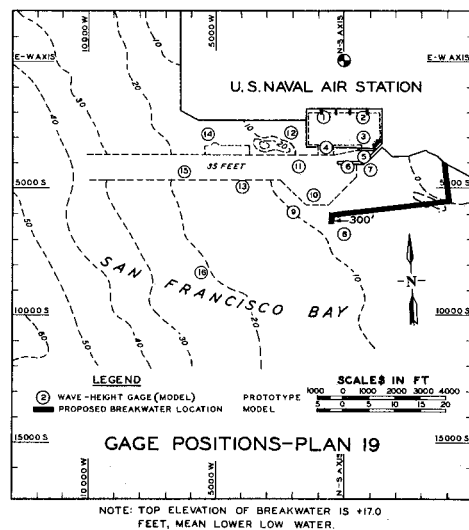
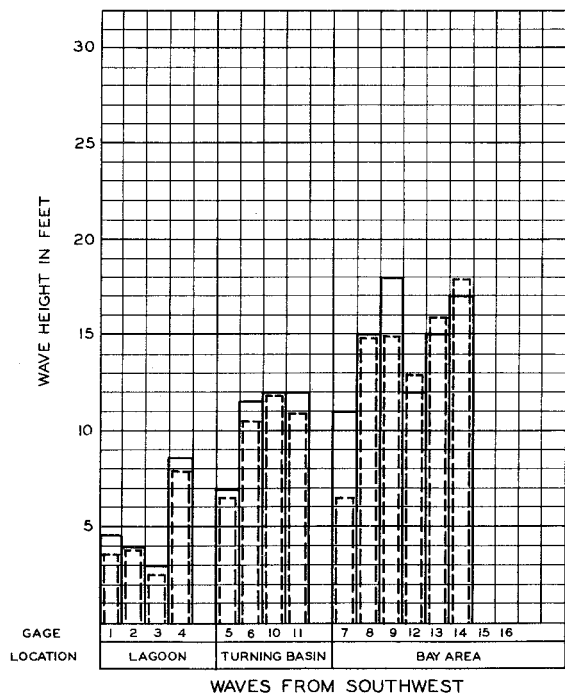
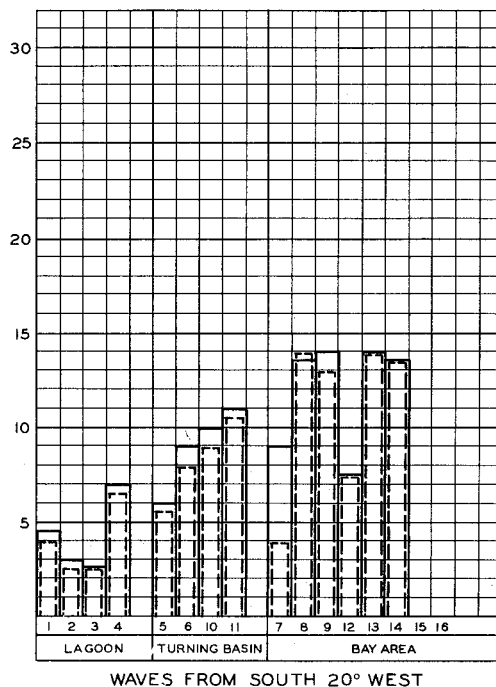
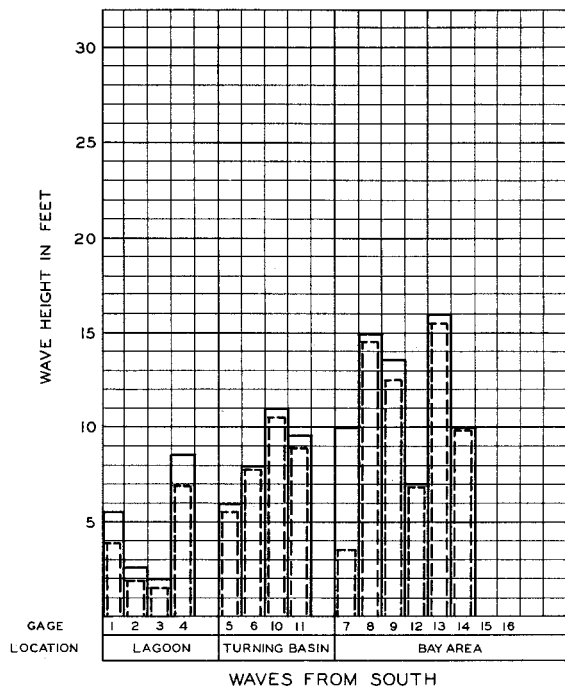
WAVES FROM SOUTH 20° WEST



WAVES FROM SOUTHWEST

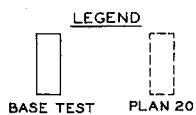
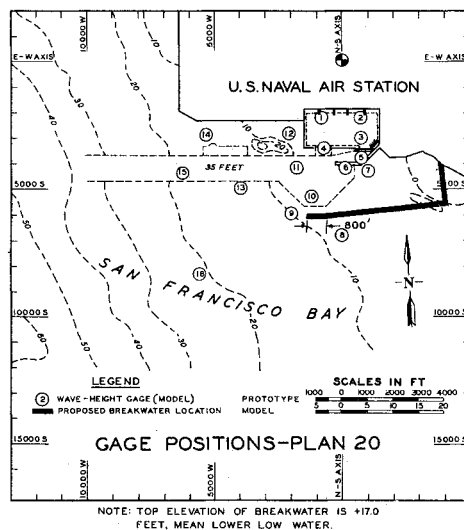
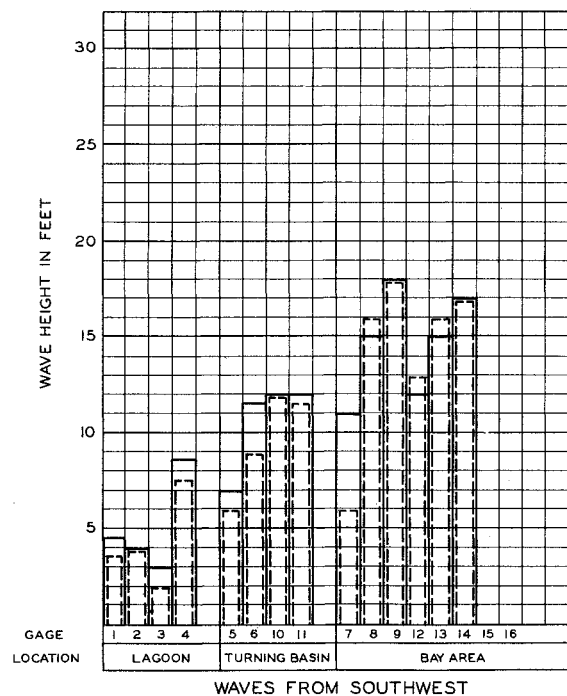
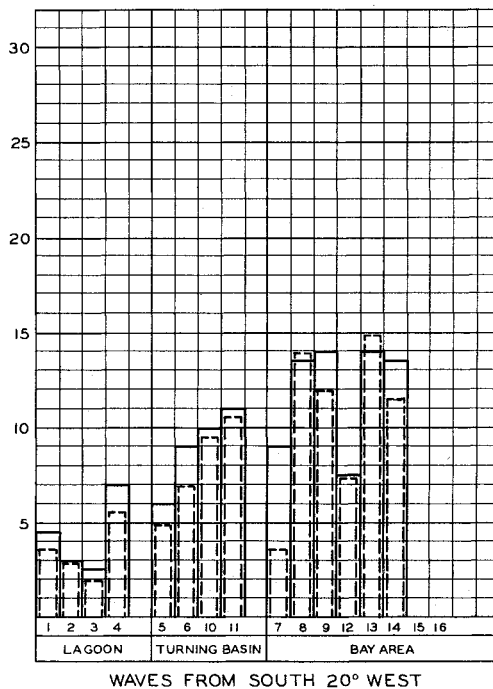
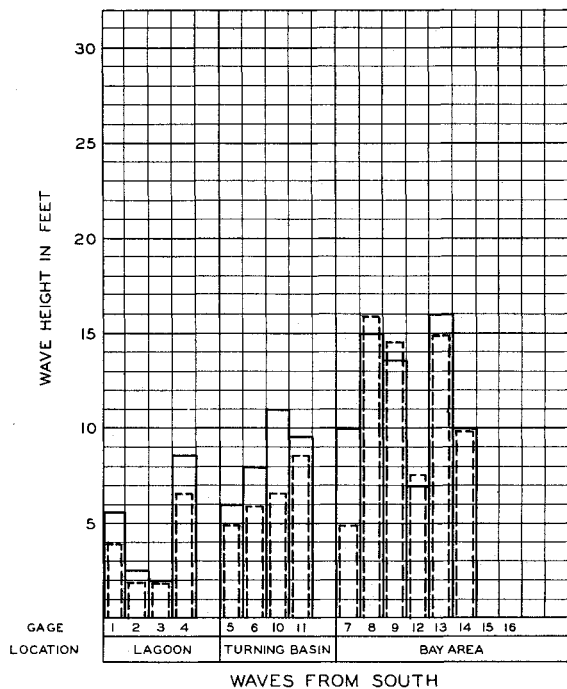


MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA
COMPARISON OF WAVE HEIGHTS
PLAN 17C AND PLAN 18B



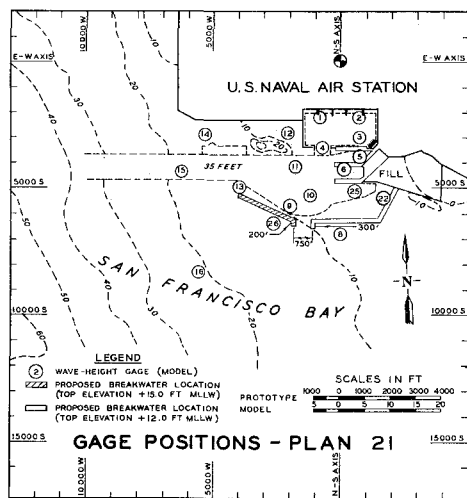
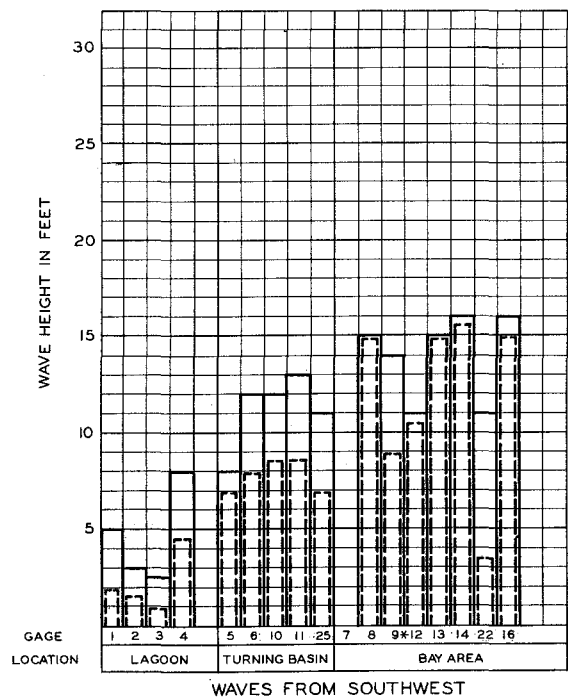
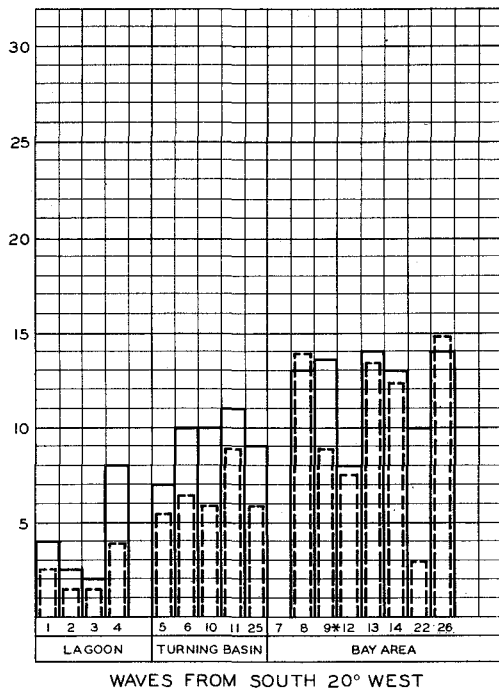
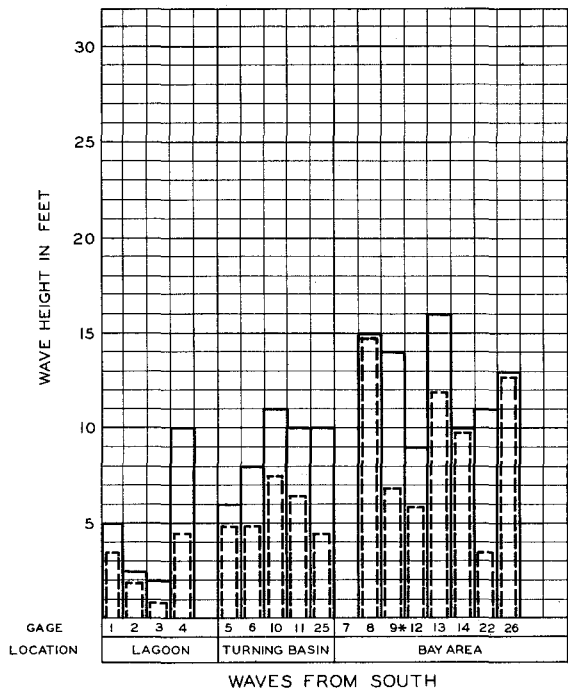
MODEL STUDY OF BREAKWATER LOCATION
U. S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN 19



MODEL STUDY OF BREAKWATER LOCATION
U. S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

COMPARISON OF WAVE HEIGHTS
BASE TEST AND PLAN 20

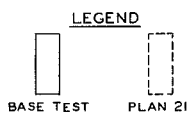


TEST CONDITIONS

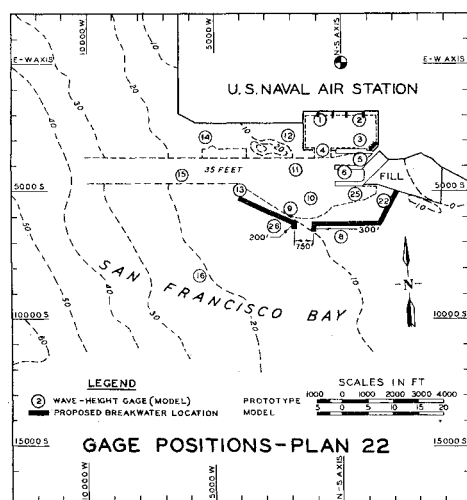
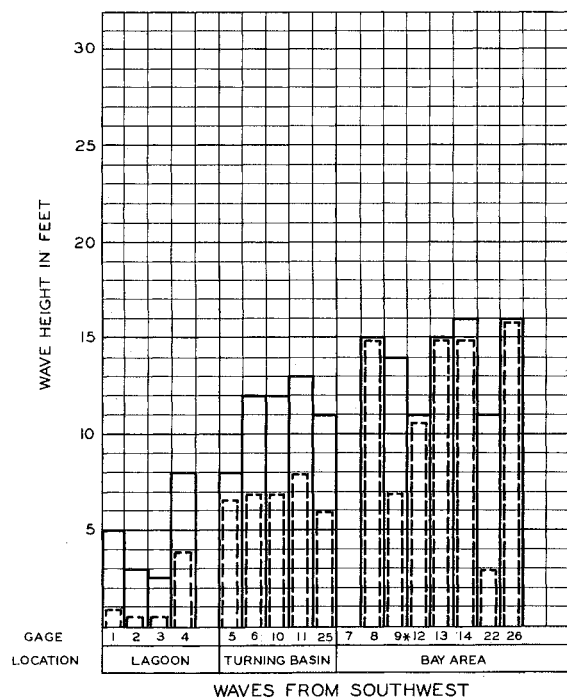
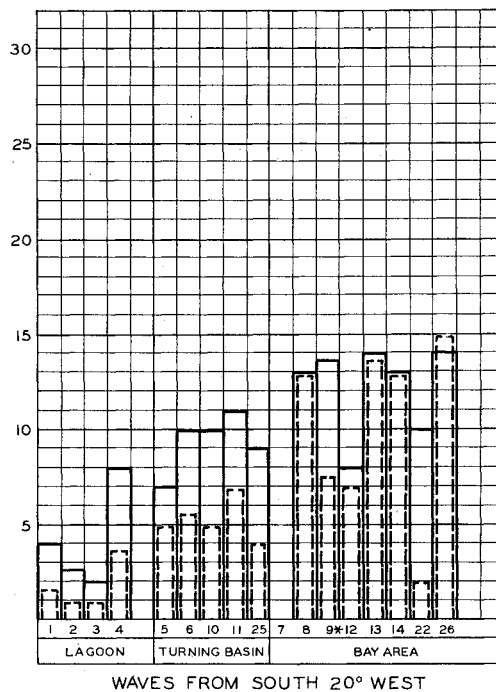
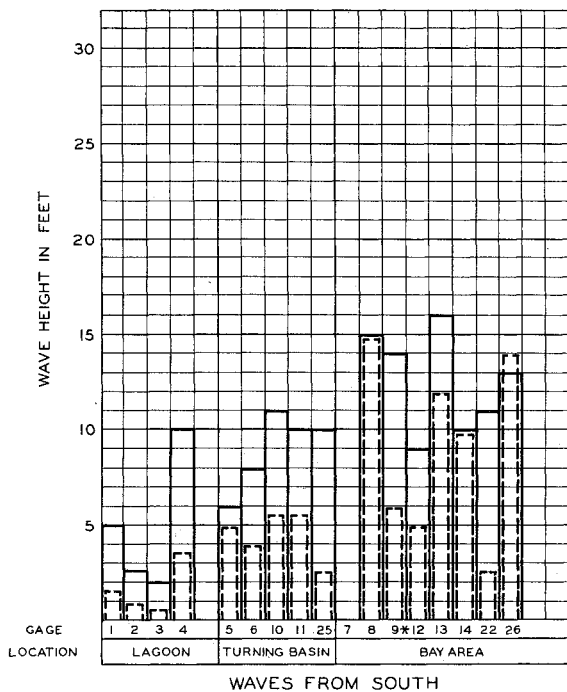
WAVE HEIGHT IN PROBLEM AREA APPROXIMATELY 10 FEET
WATER-SURFACE ELEVATION +9.6 FEET MLLW

MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

COMPARISON OF WAVE HEIGHTS BASE TEST AND PLAN 21



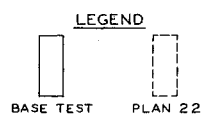
* FOR TEST OF PLAN 21 MODEL WAVE-HEIGHT GAGE
NUMBER 9 WAS LOCATED IN TURNING BASIN.



NOTE: TOP ELEVATION OF BREAKWATER IS +17.0 FEET
MEAN LOWER LOW WATER

TEST CONDITIONS

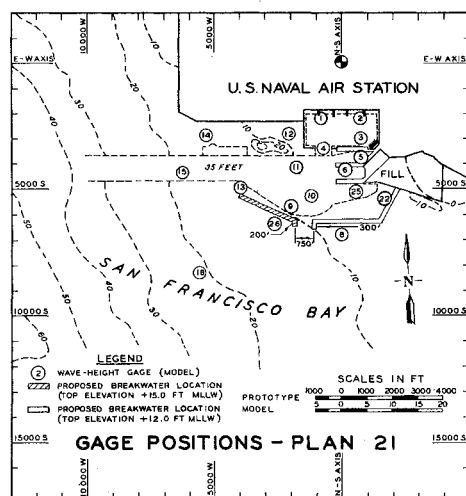
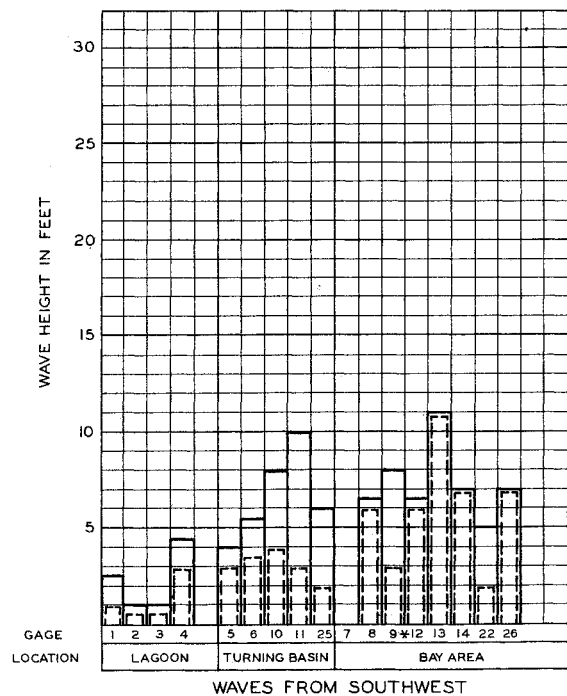
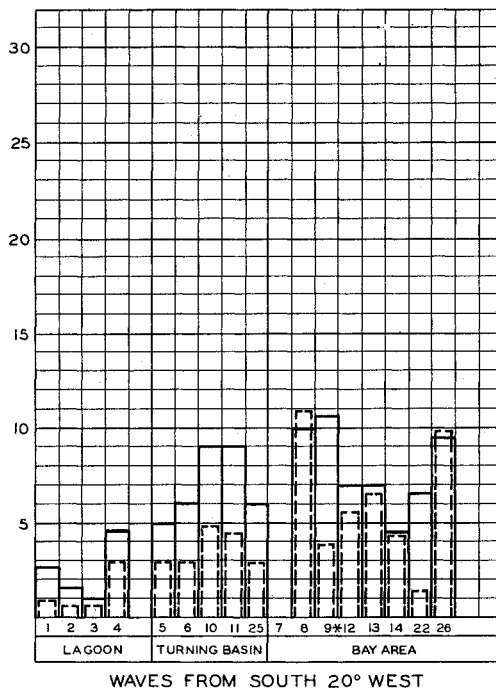
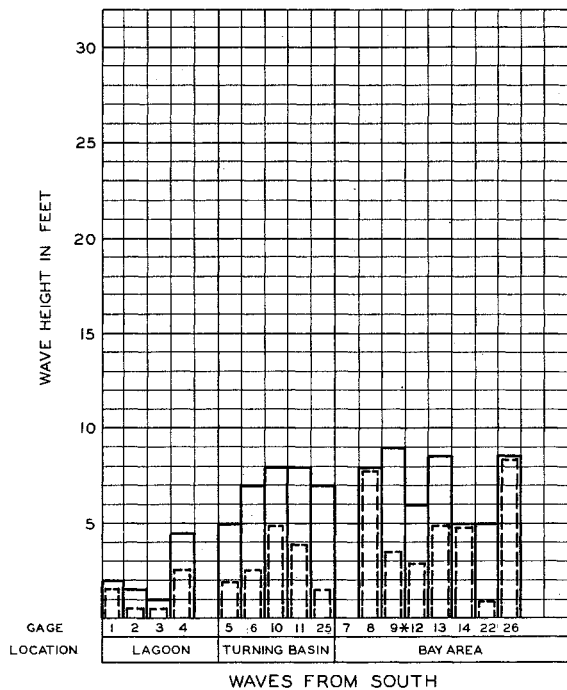
WAVE HEIGHT IN PROBLEM AREA APPROXIMATELY 10 FEET
WATER-SURFACE ELEVATION +9.6 FEET M.L.W.



*FOR TEST OF PLAN 22 MODEL WAVE-HEIGHT GAGE
NUMBER 9 WAS LOCATED IN TURNING BASIN.

MODEL STUDY OF BREAKWATER LOCATION U.S. NAVAL AIR STATION ALAMEDA, CALIFORNIA

COMPARISON OF WAVE HEIGHTS BASE TEST AND PLAN 22

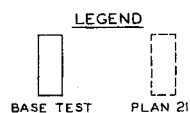


TEST CONDITIONS

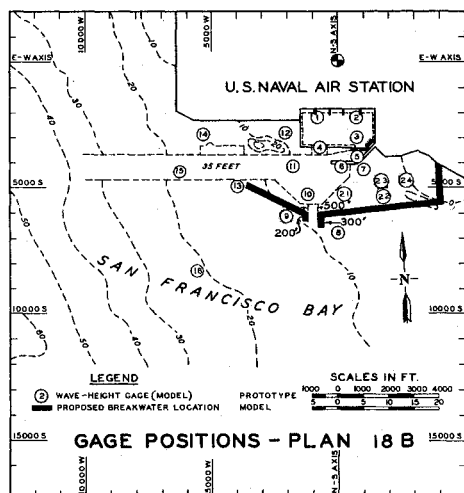
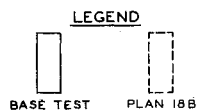
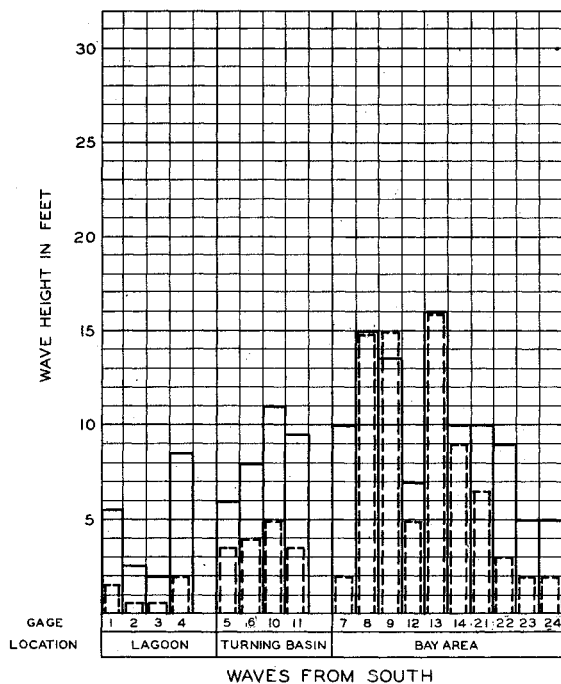
WAVE HEIGHT IN PROBLEM AREA APPROXIMATELY 7 FEET.
WATER-SURFACE ELEVATION +7.0 FEET MLLW

MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

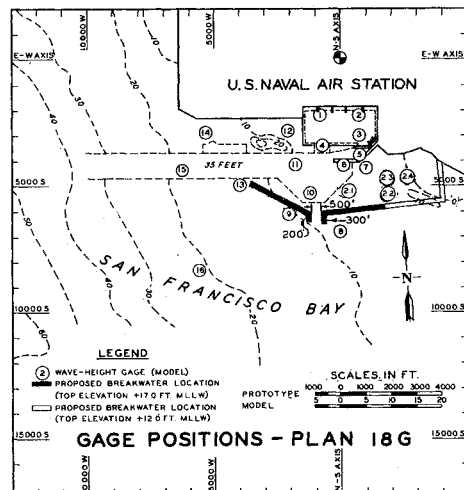
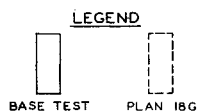
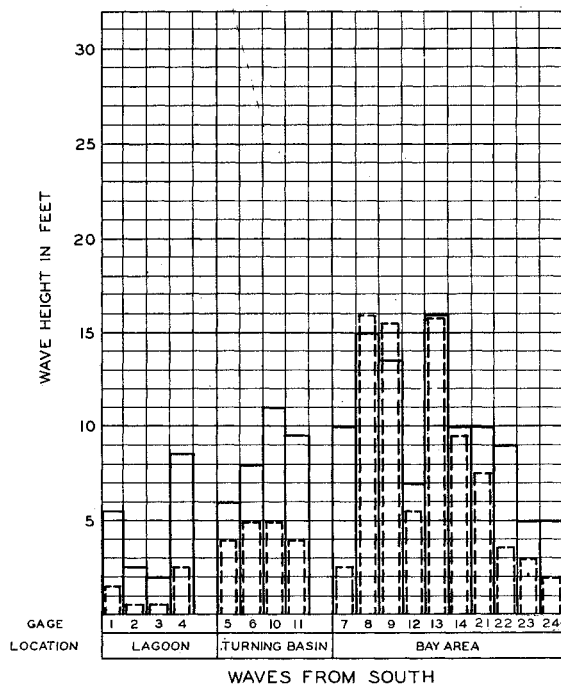
COMPARISON OF WAVE HEIGHTS BASE TEST AND PLAN 21



*FOR TEST OF PLAN 21 MODEL WAVE-HEIGHT GAGE
NUMBER 9 WAS LOCATED IN TURNING BASIN.

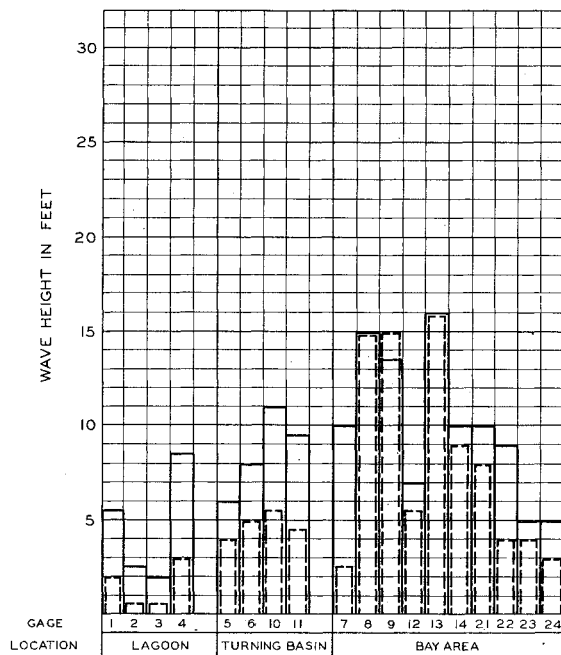


NOTE: TOP ELEVATION OF BREAKWATER IS +17.0 FEET, MEAN LOWER LOW WATER.

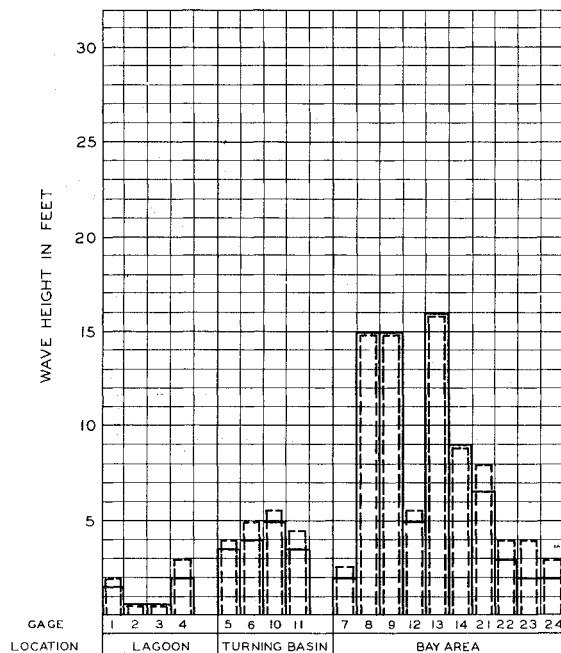
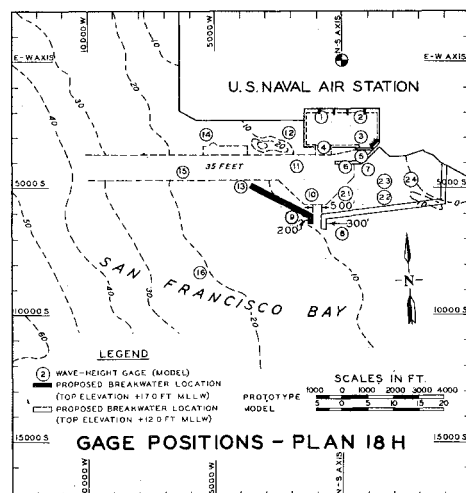
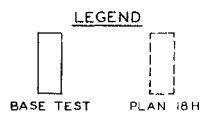


MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

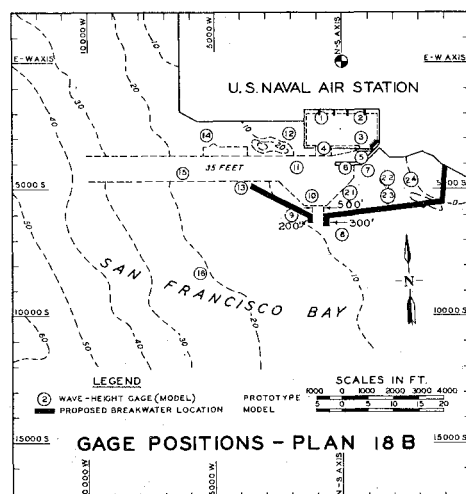
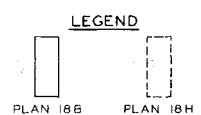
COMPARISON OF WAVE HEIGHTS
BASE TEST, PLAN 18B, PLAN 18G



WAVES FROM SOUTH



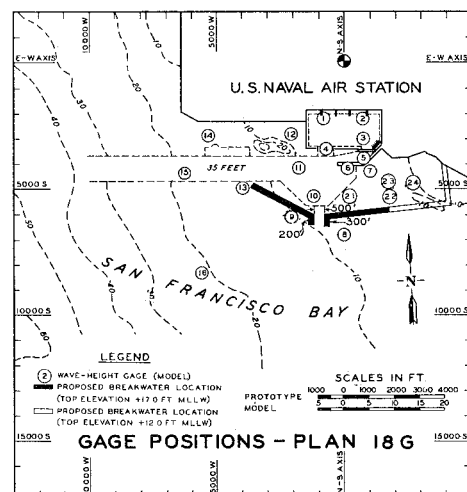
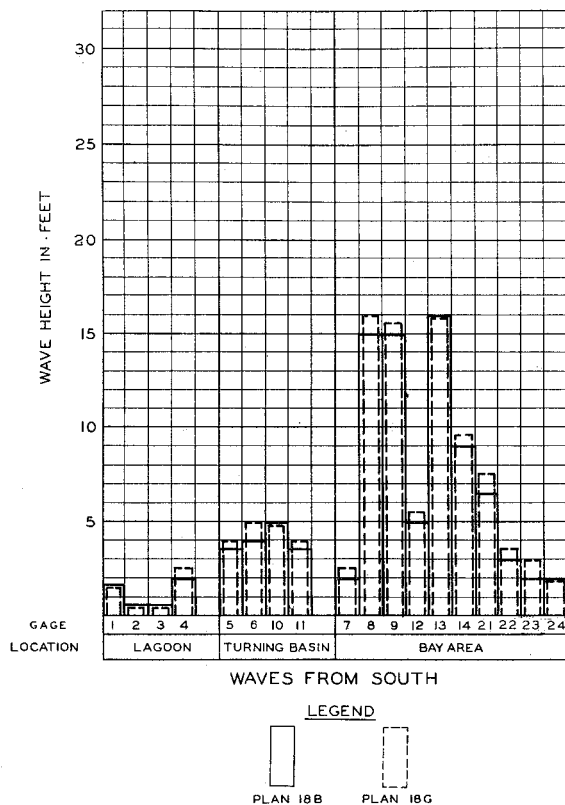
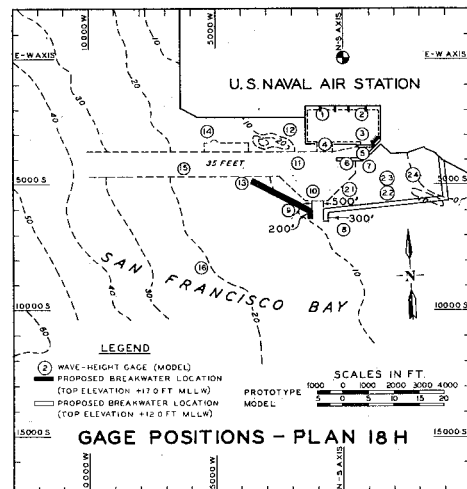
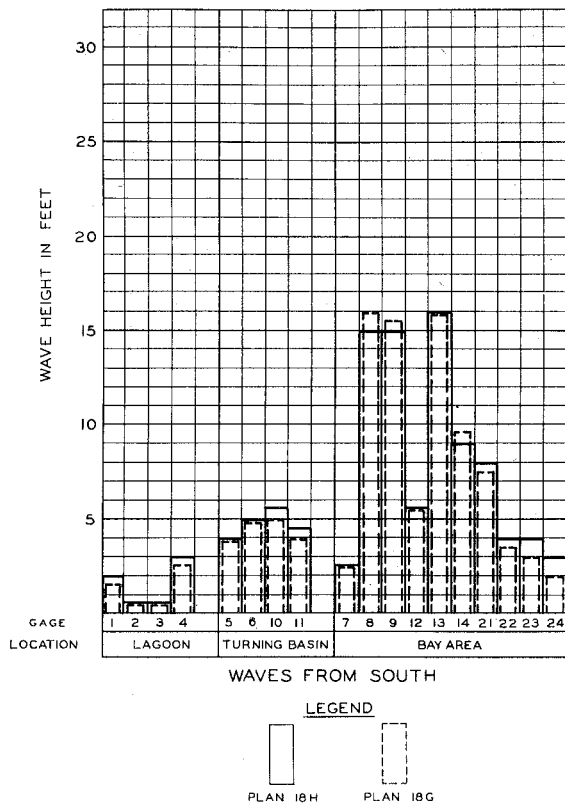
WAVES FROM SOUTH



NOTE: TOP ELEVATION OF BREAKWATER IS +17.0 FEET, MEAN LOWER LOW WATER.

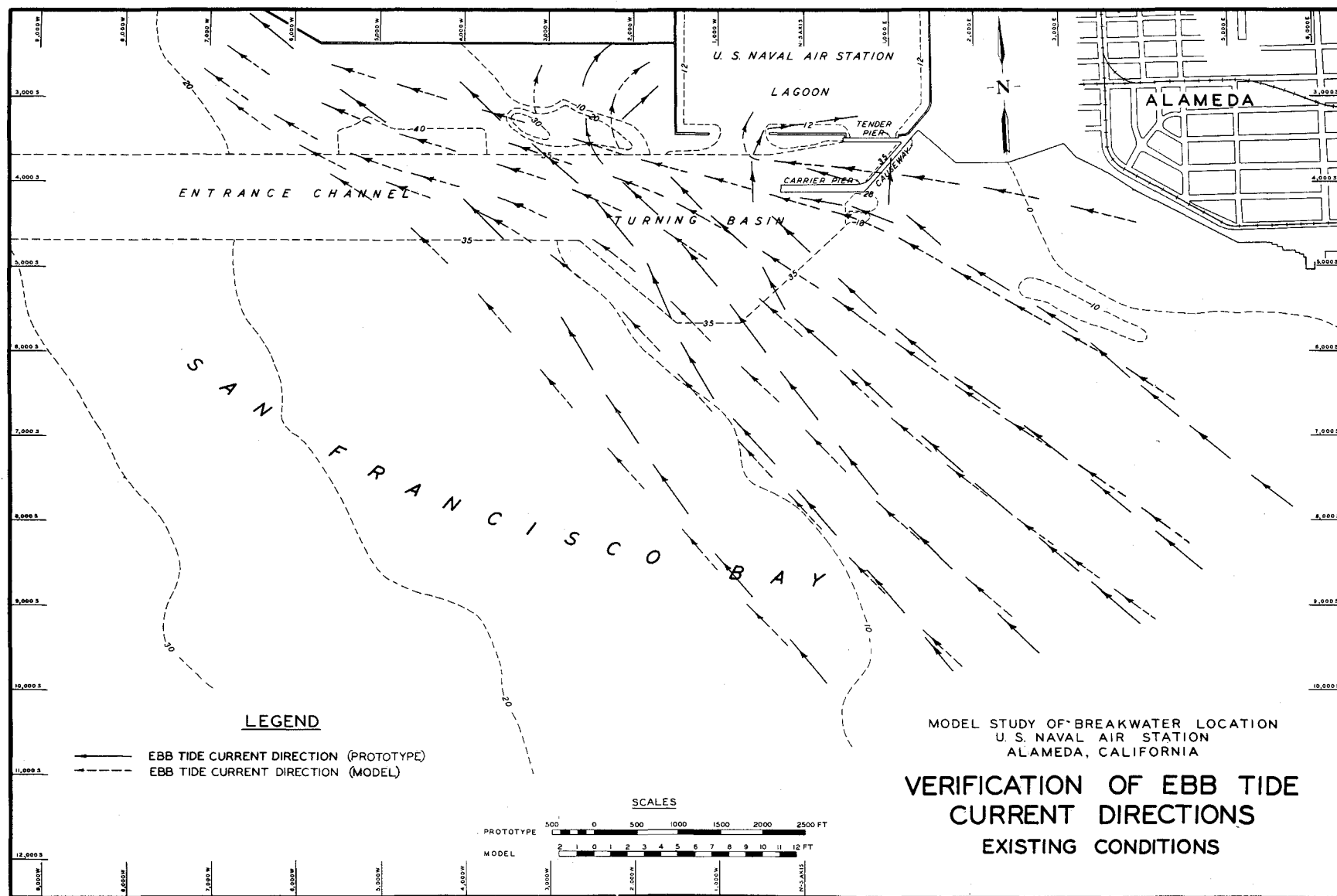
MODEL STUDY OF BREAKWATER LOCATION
 U.S. NAVAL AIR STATION
 ALAMEDA, CALIFORNIA

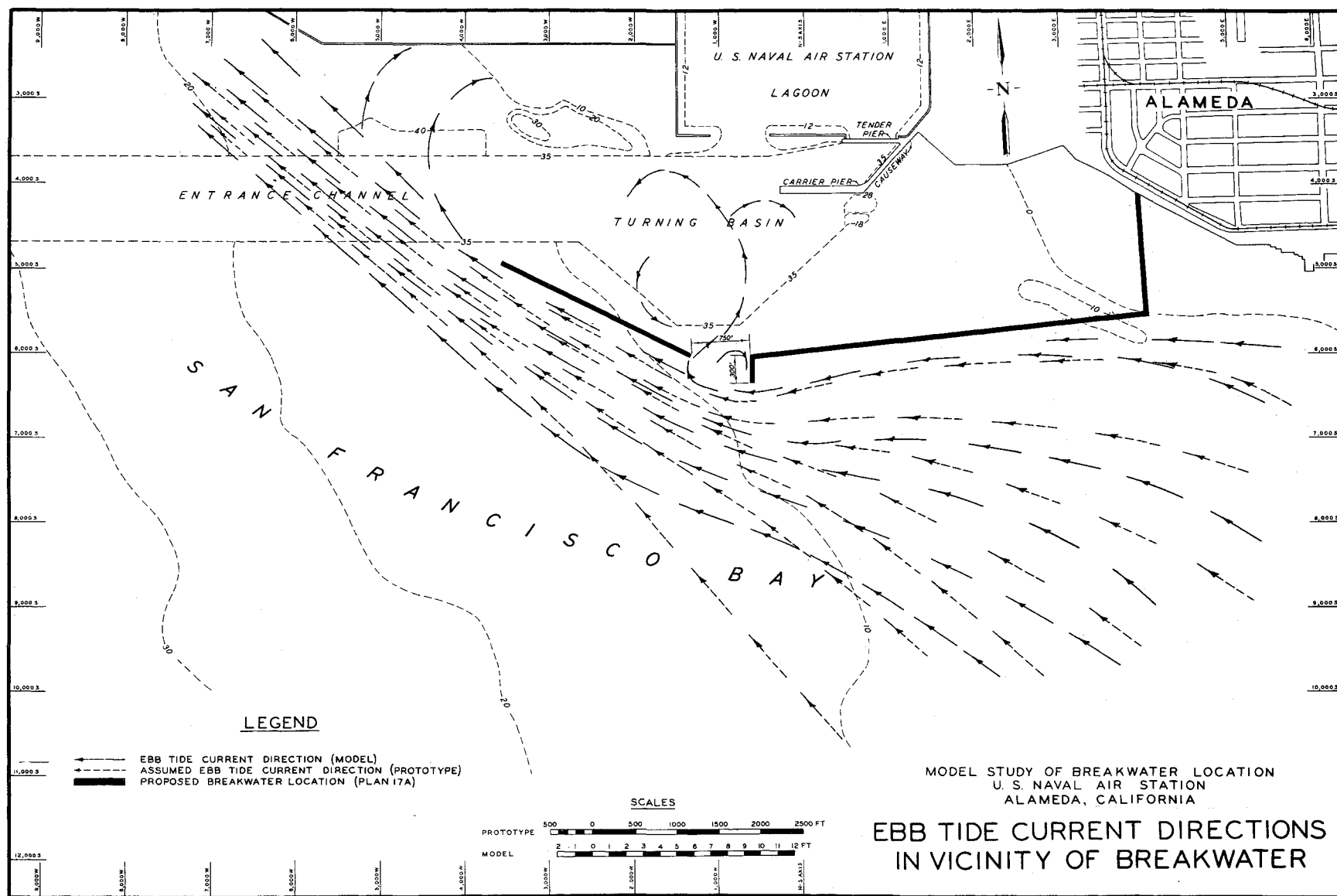
**COMPARISON OF WAVE HEIGHTS
 BASE TEST, PLAN 18B, PLAN 18H**



MODEL STUDY OF BREAKWATER LOCATION
 U.S. NAVAL AIR STATION
 ALAMEDA, CALIFORNIA

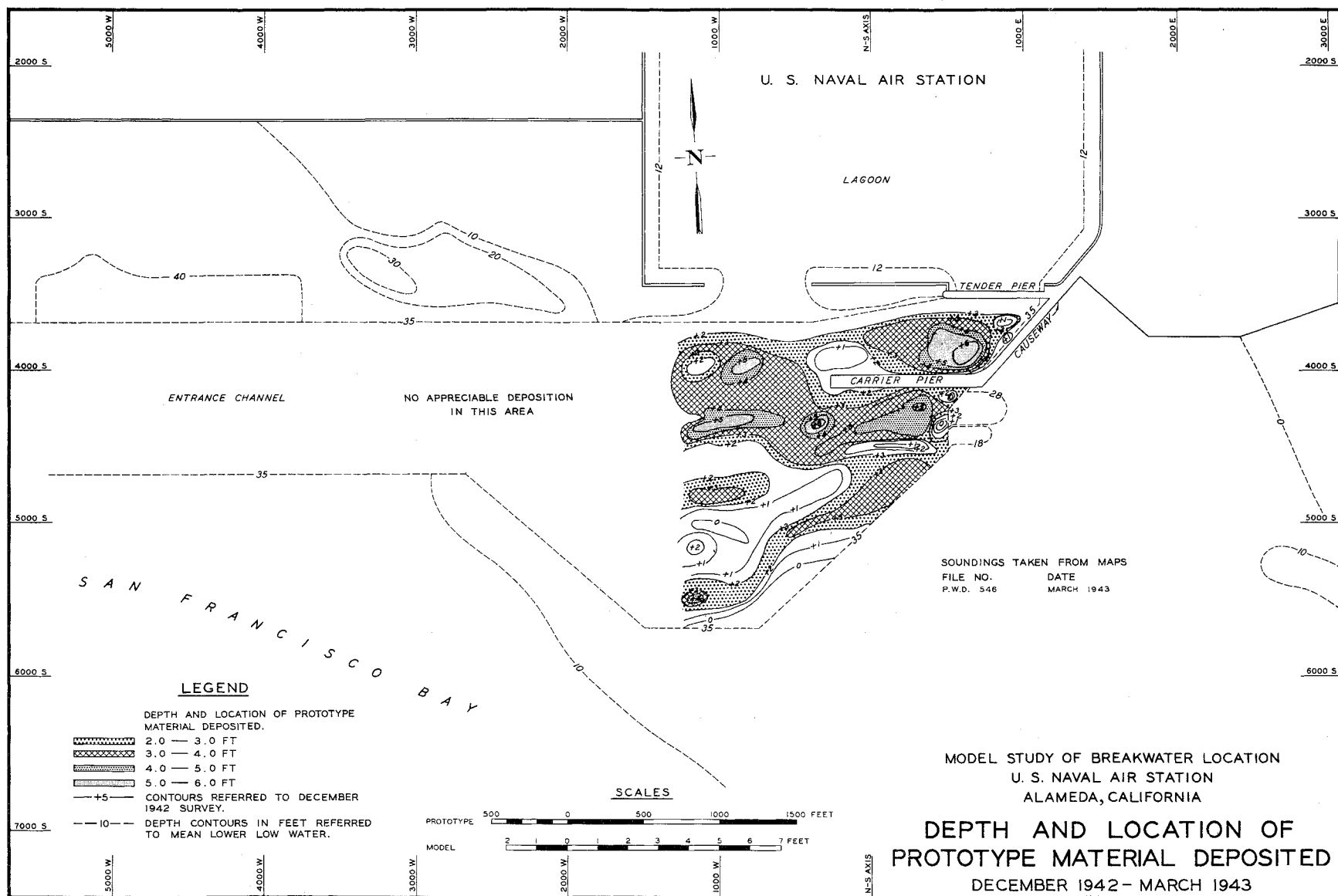
**COMPARISON OF WAVE HEIGHTS
 PLAN 18B, PLAN 18G, PLAN 18H**

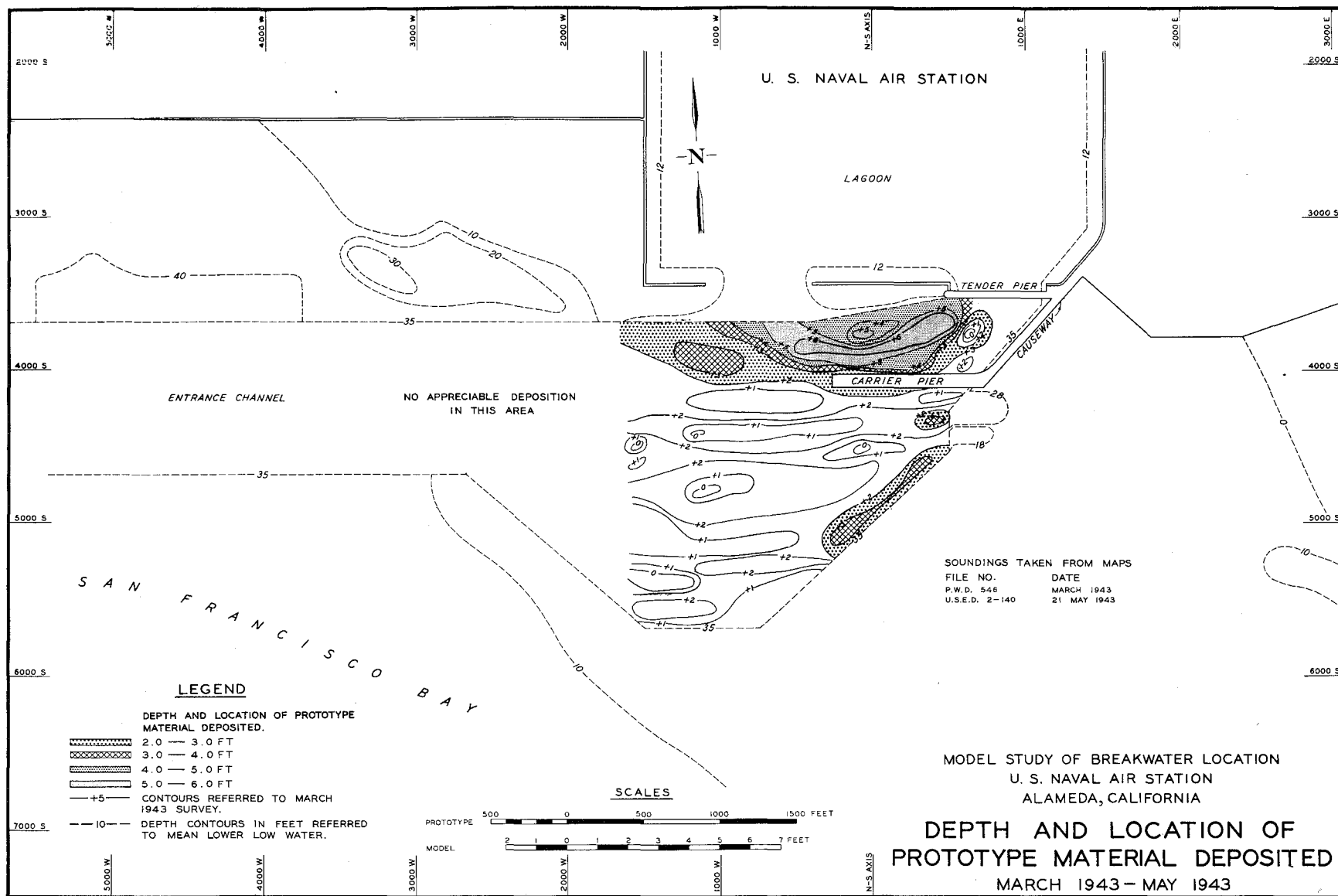


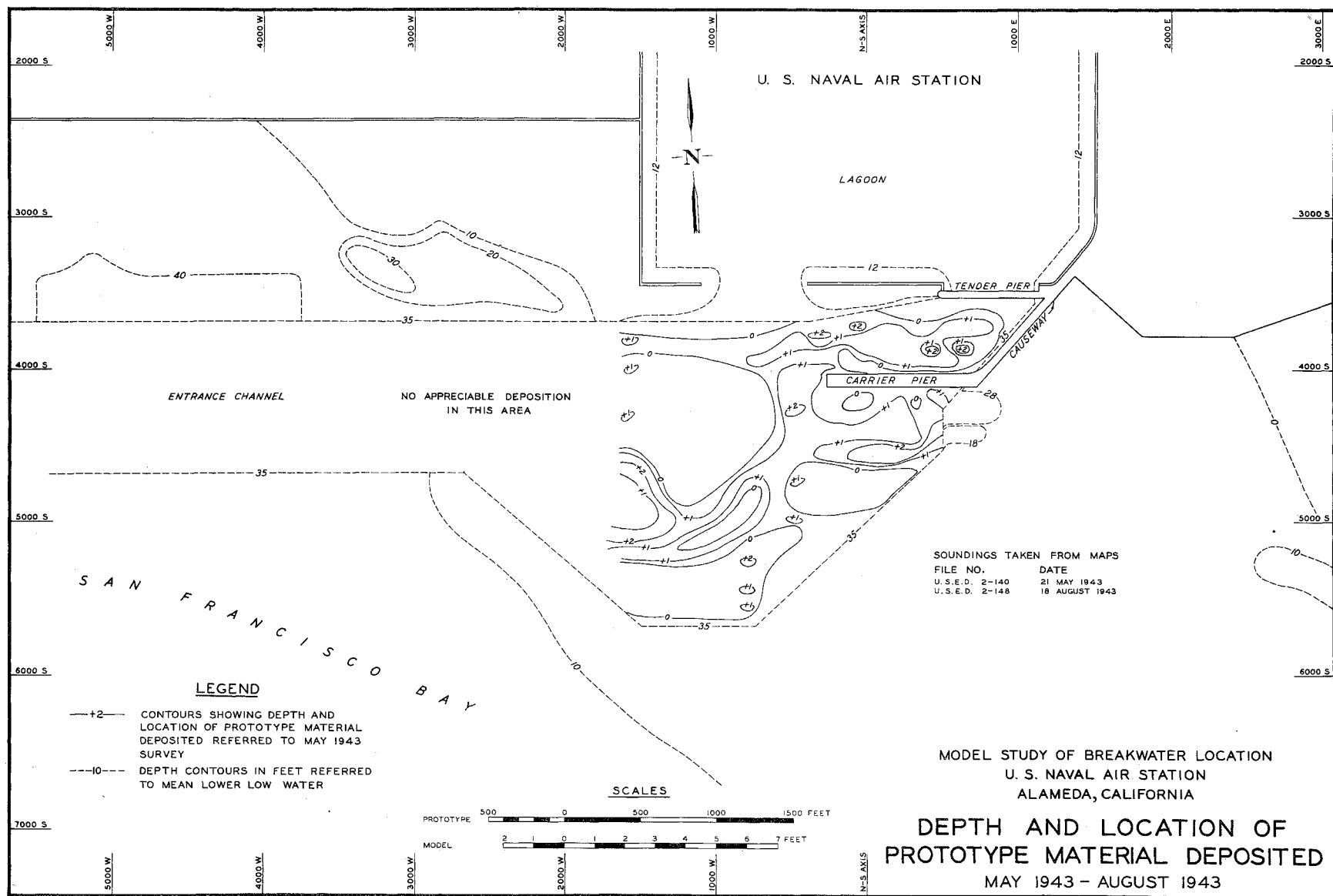


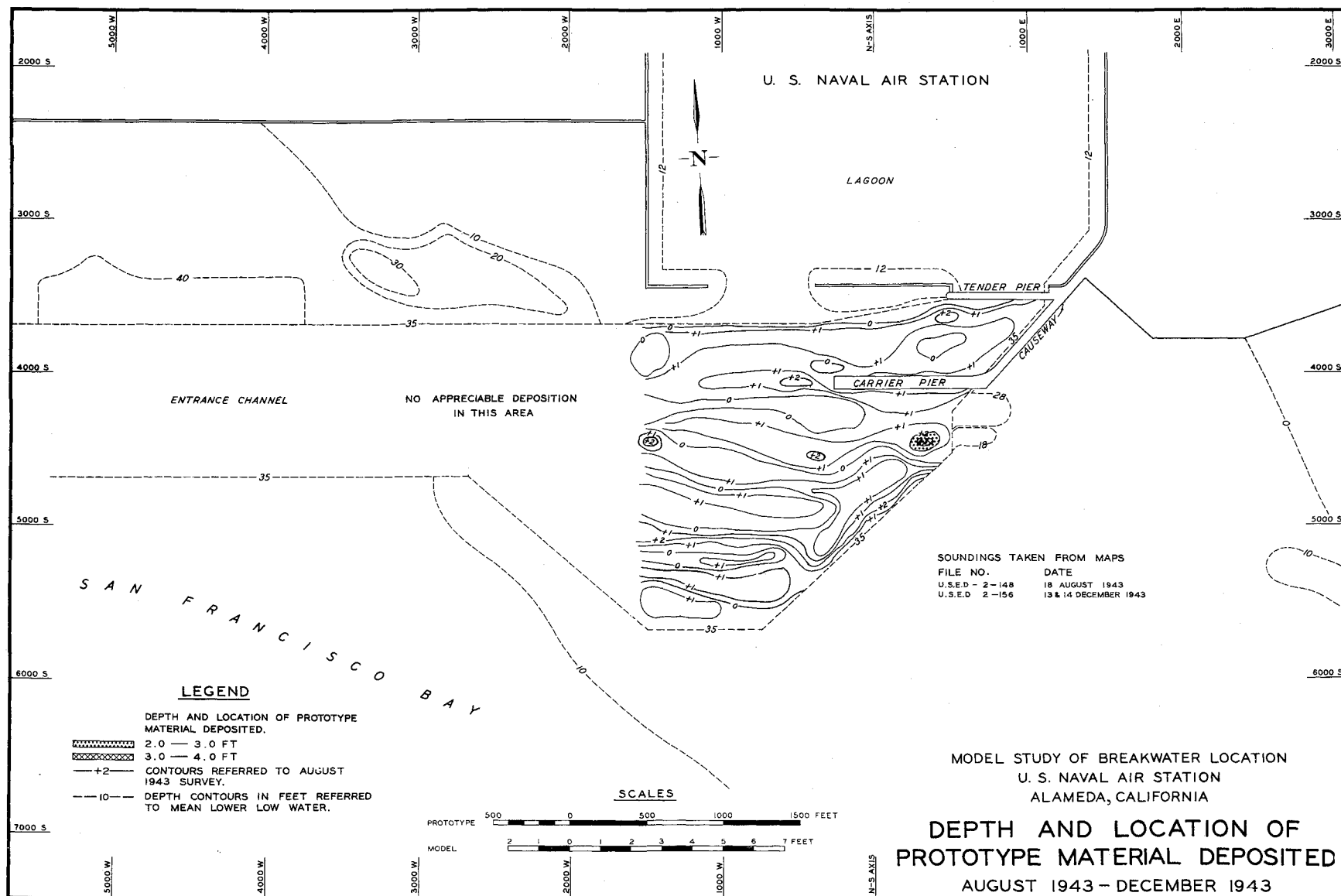
MODEL STUDY OF BREAKWATER LOCATION
U. S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

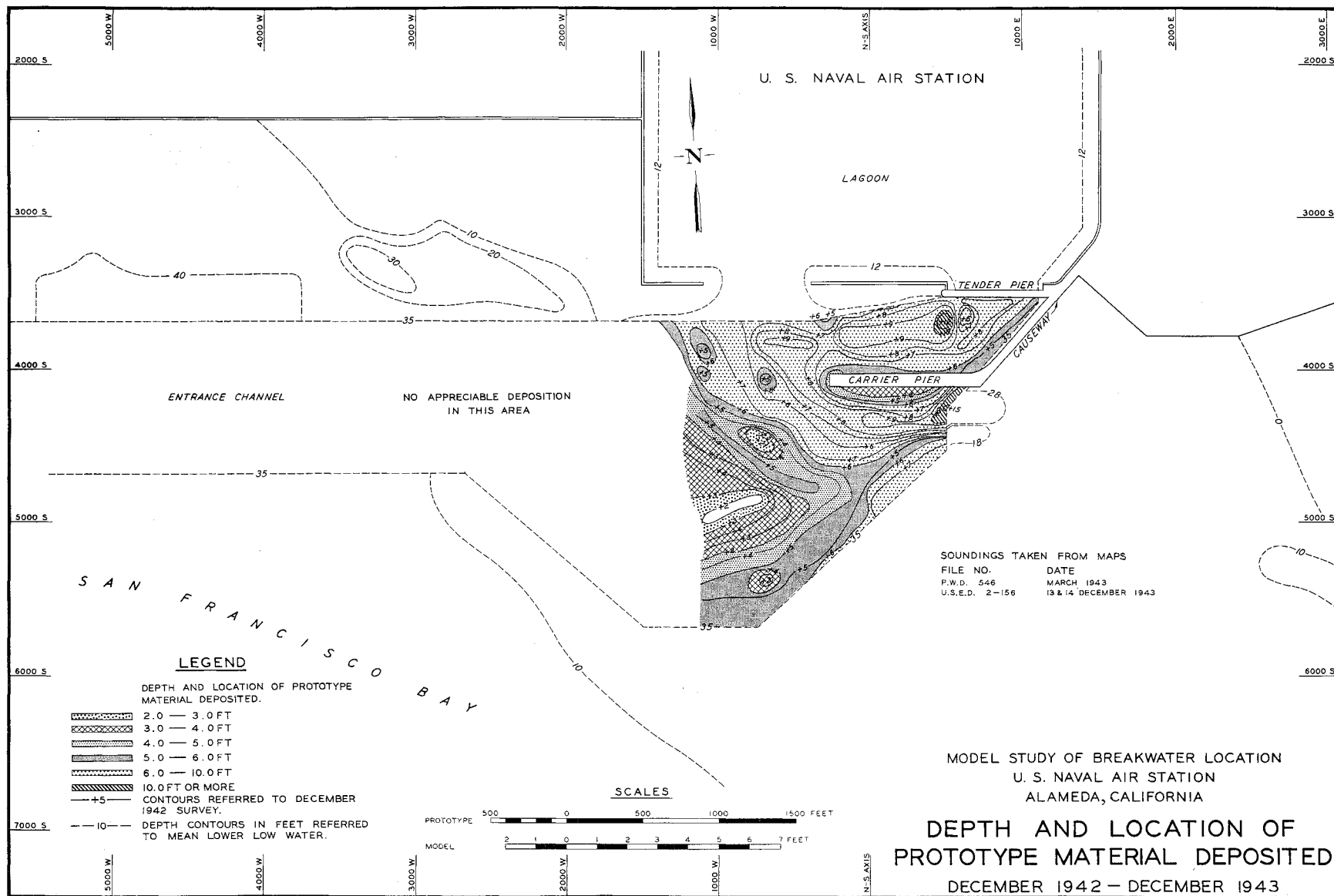
**EBB TIDE CURRENT DIRECTIONS
IN VICINITY OF BREAKWATER**

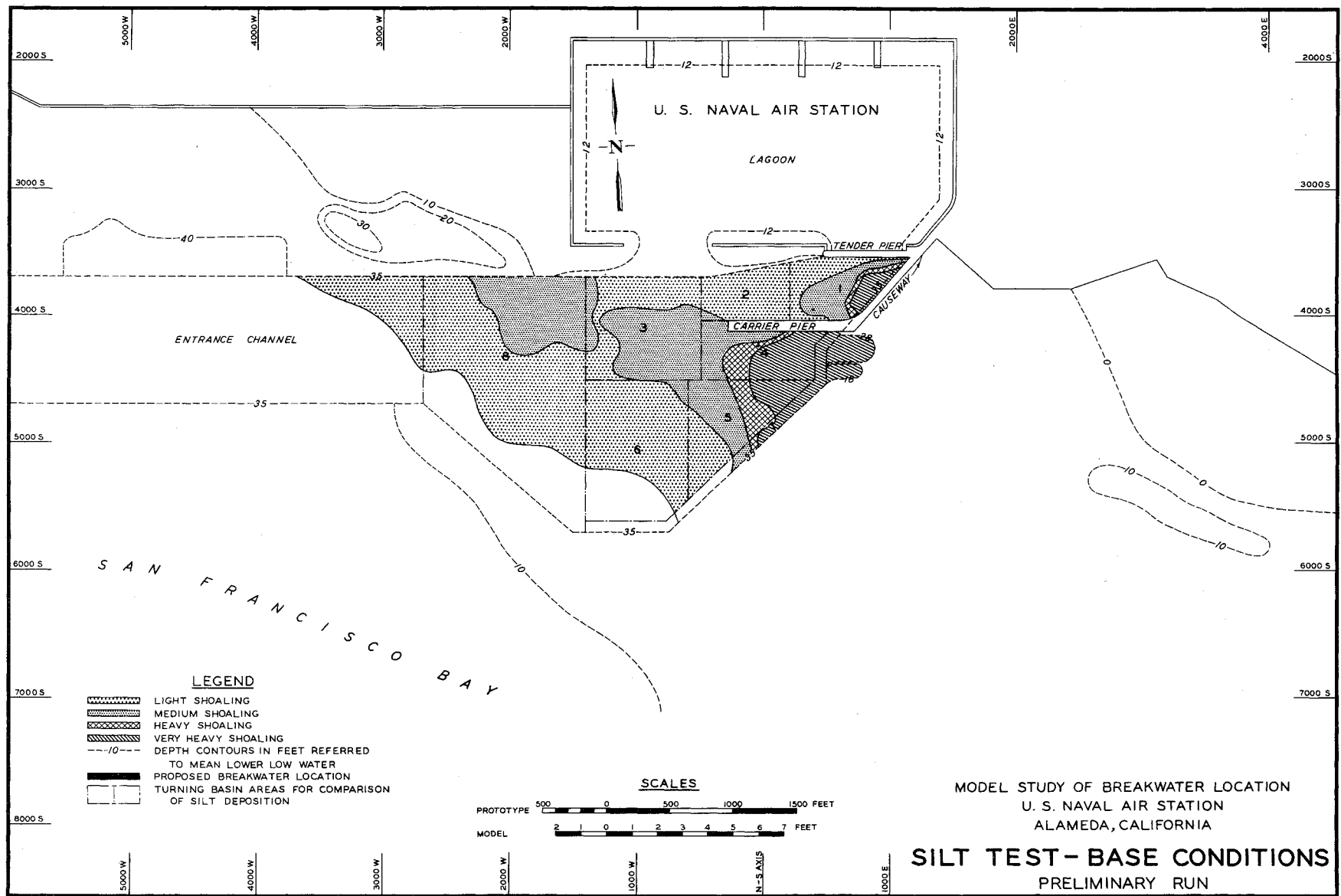


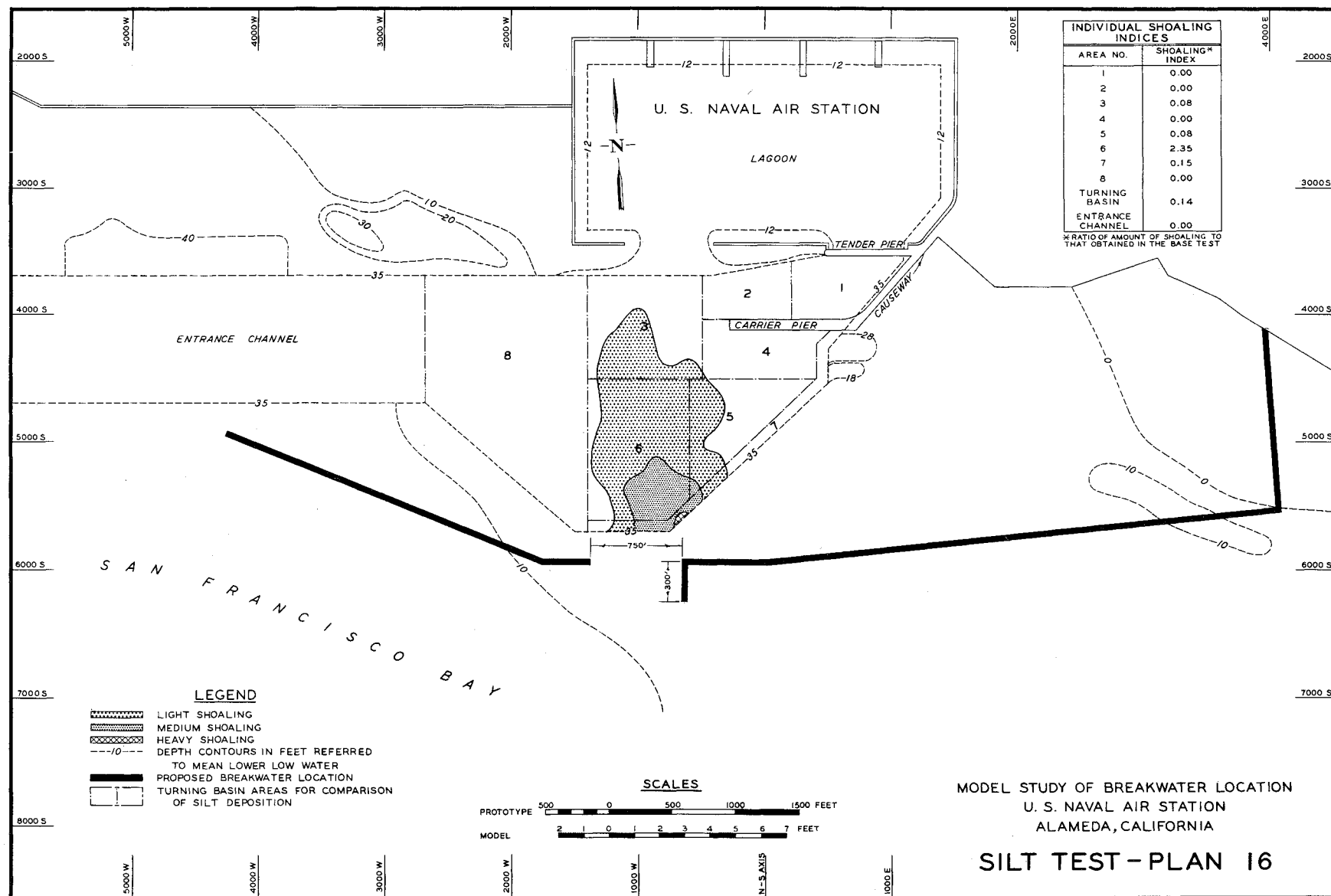


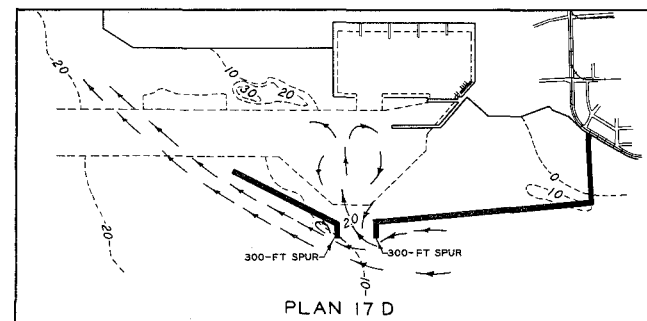
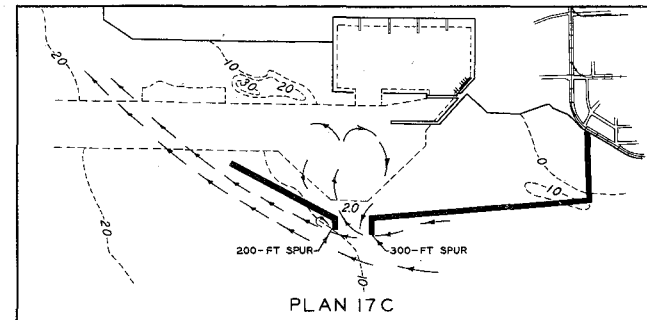
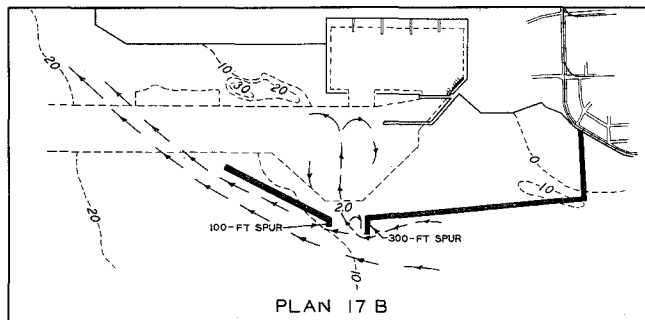
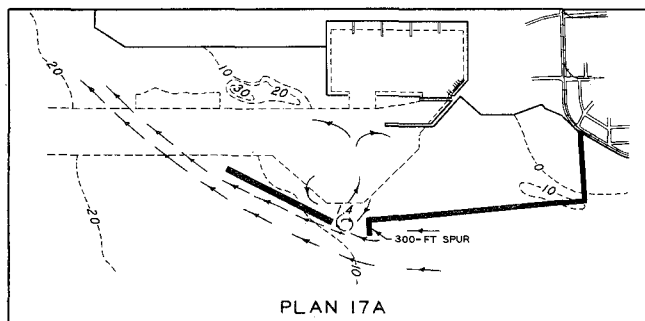
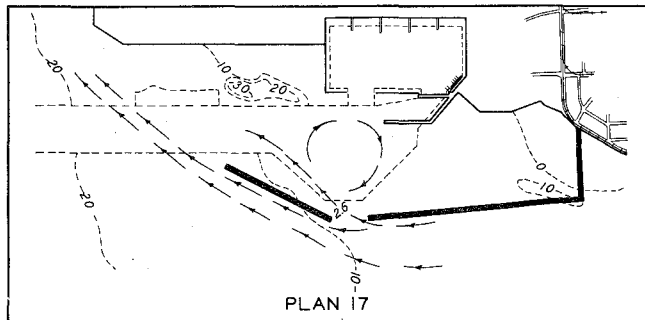












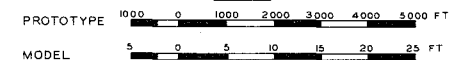
LEGEND

- BREAKWATER LOCATIONS
- 2.6 EBB TIDE CURRENT - FEET PER SECOND PROTOTYPE

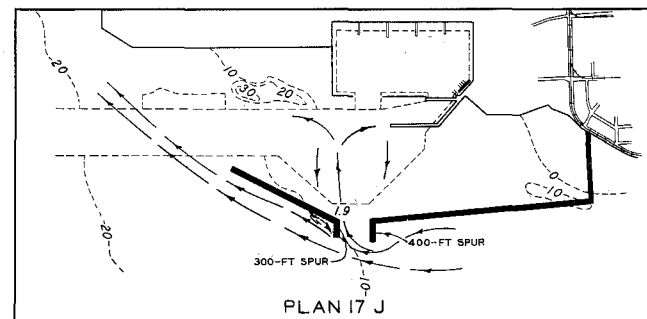
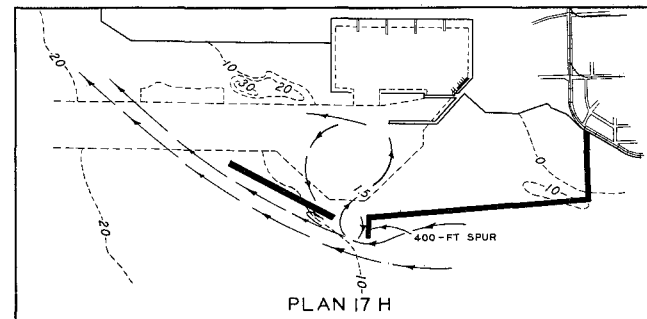
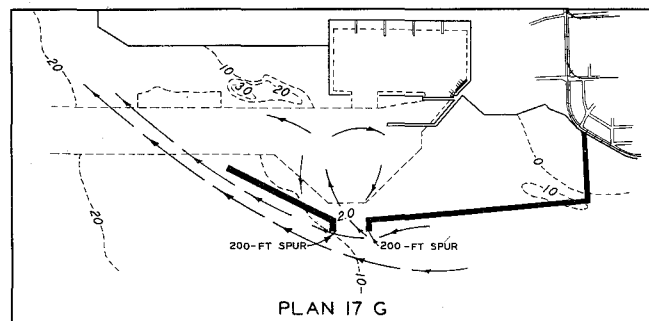
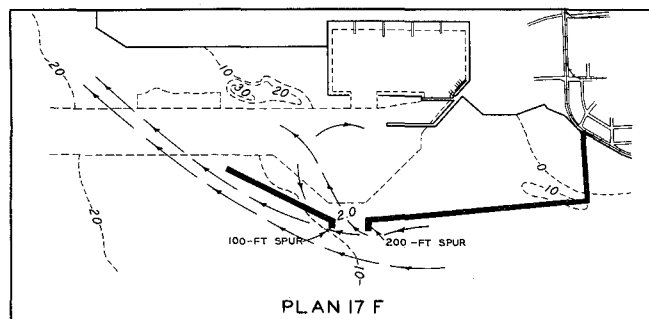
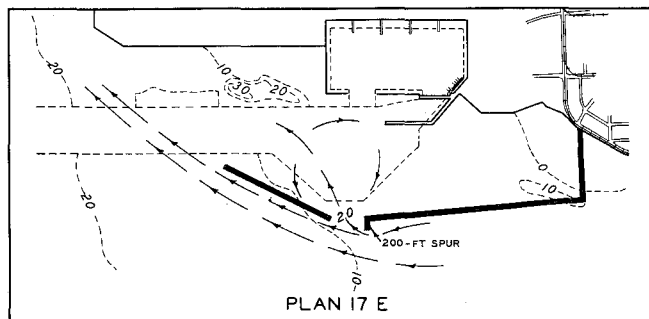
MODEL STUDY OF BREAKWATER LOCATION
U. S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

MAGNITUDE AND DIRECTION OF CURRENTS AT NAVIGATION OPENING

SCALES



NOTE: WIDTH OF NAVIGATION OPENING EQUALS 750 FT.
CURRENT DIRECTION AND MAGNITUDE MEASURED
WITHOUT WAVE ACTION.

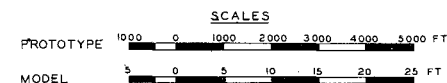


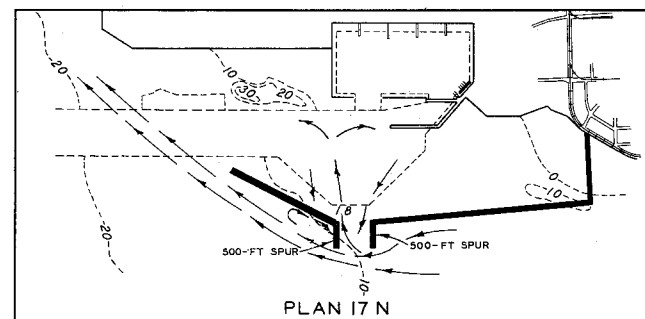
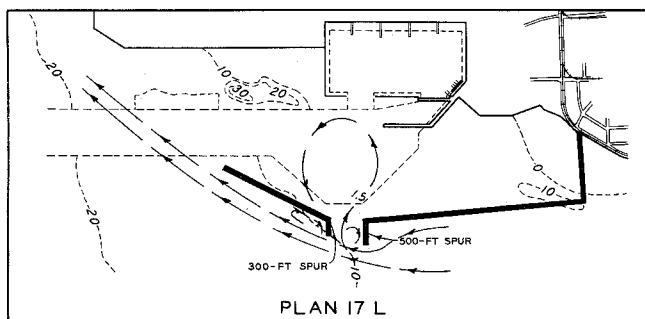
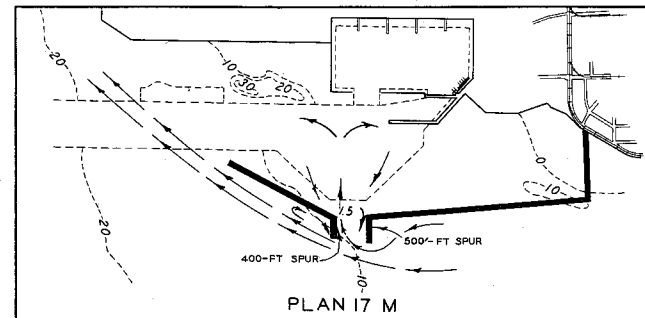
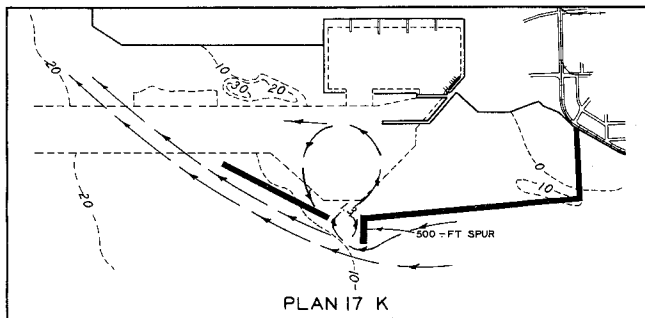
LEGEND

- BREAKWATER LOCATIONS
- EBB TIDE CURRENT - FEET PER SECOND PROTOTYPE

MODEL STUDY OF BREAKWATER LOCATION U. S. NAVAL AIR STATION ALAMEDA, CALIFORNIA MAGNITUDE AND DIRECTION OF CURRENTS AT NAVIGATION OPENING

NOTE: WIDTH OF NAVIGATION OPENING EQUALS 750 FT.
CURRENT DIRECTION AND MAGNITUDE MEASURED
WITHOUT WAVE ACTION.



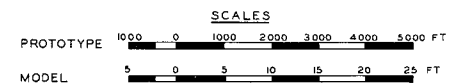


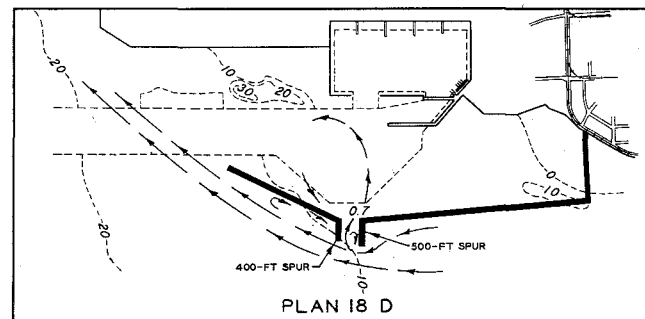
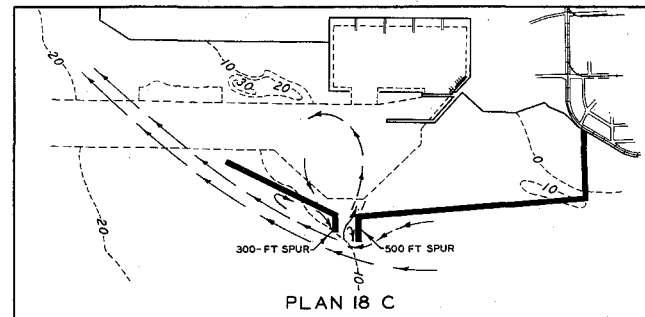
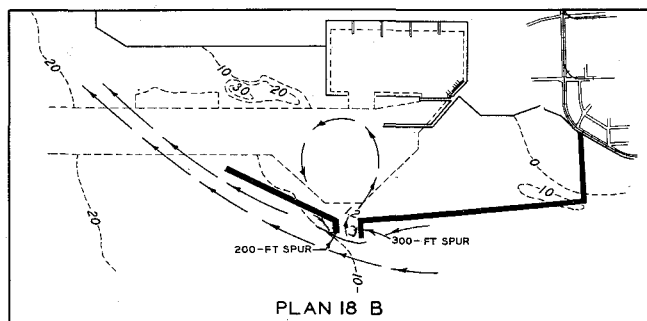
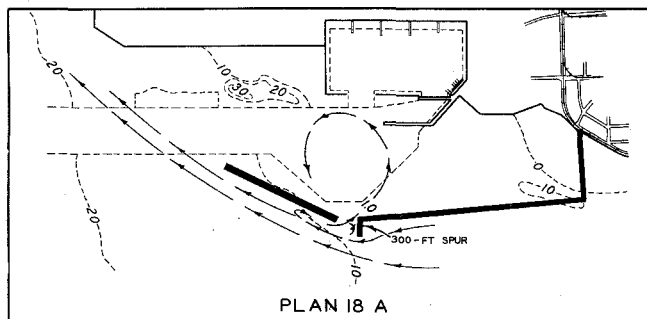
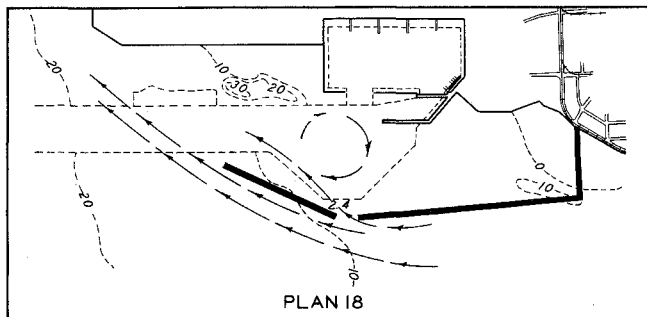
LEGEND

- BREAKWATER LOCATIONS
- EBB TIDE CURRENT - FEET
PER SECOND PROTOTYPE

MODEL STUDY OF BREAKWATER LOCATION U. S. NAVAL AIR STATION ALAMEDA, CALIFORNIA MAGNITUDE AND DIRECTION OF CURRENTS AT NAVIGATION OPENING

NOTE: WIDTH OF NAVIGATION OPENING EQUALS 750 FT.
CURRENT DIRECTION AND MAGNITUDE MEASURED
WITHOUT WAVE ACTION.





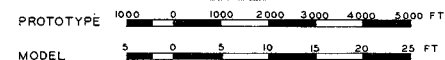
LEGEND

- BREAKWATER LOCATIONS
- 2.4 EBB TIDE CURRENT - FEET PER SECOND PROTOTYPE

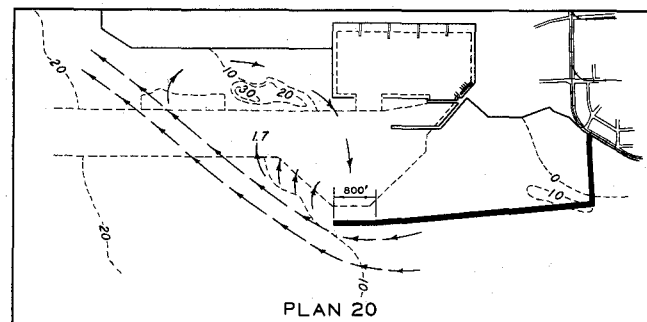
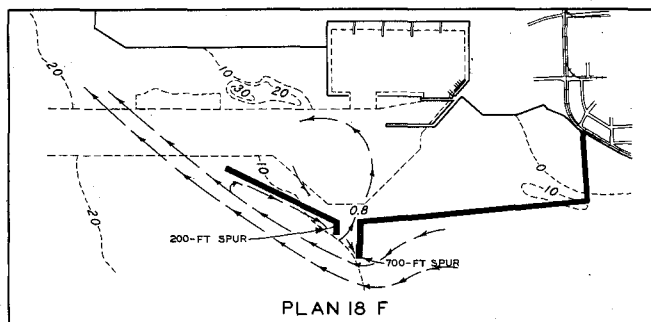
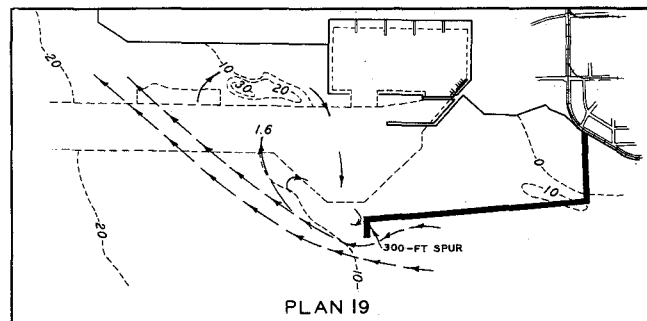
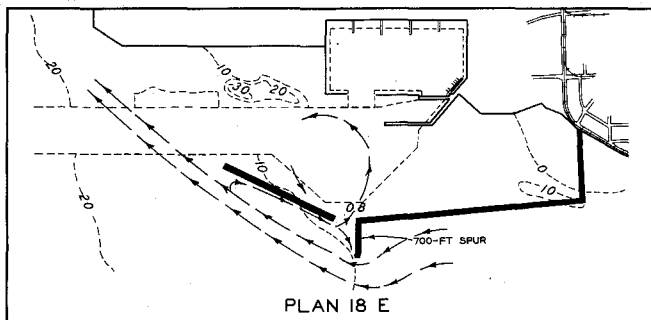
MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

MAGNITUDE AND DIRECTION OF CURRENTS AT NAVIGATION OPENING

SCALES



NOTE: WIDTH OF NAVIGATION OPENING EQUALS 500 FT.
CURRENT DIRECTION AND MAGNITUDE MEASURED
WITHOUT WAVE ACTION.



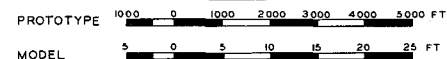
LEGEND

- BREAKWATER LOCATIONS
- ← 0.8 — EBB TIDE CURRENT — FEET
PER SECOND PROTOTYPE

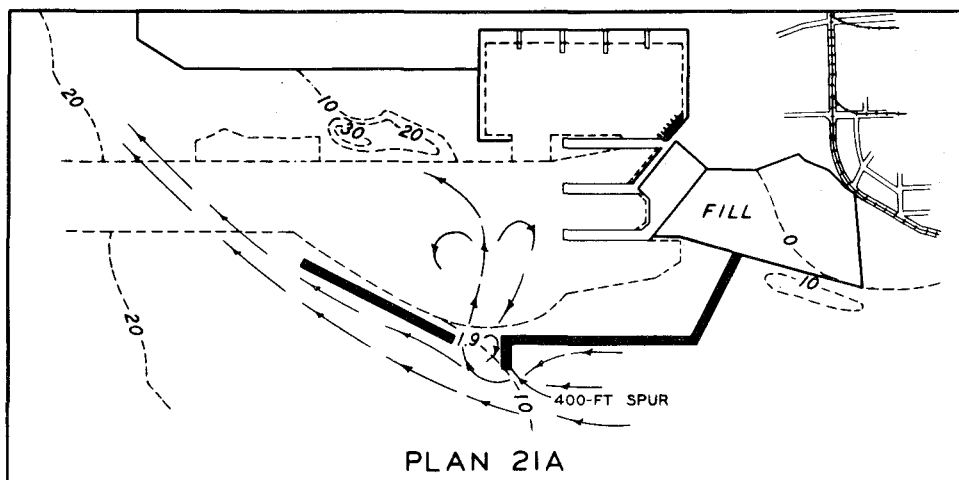
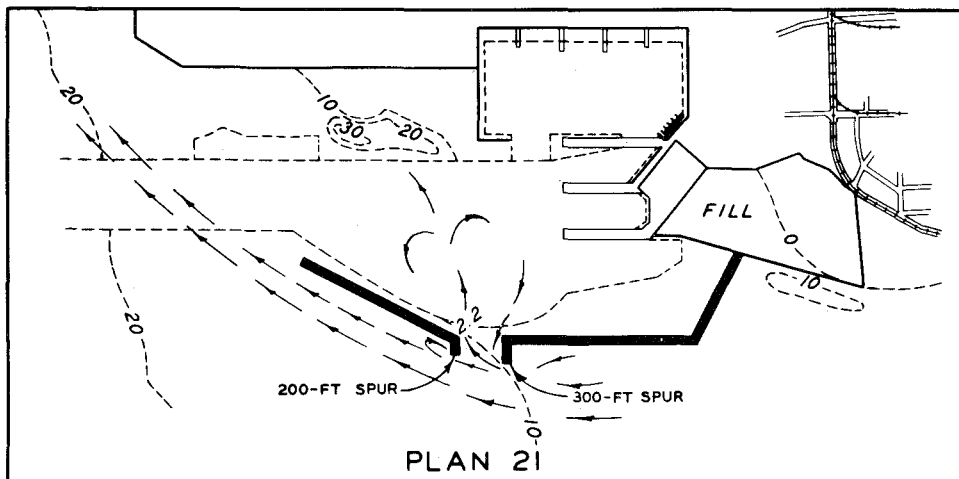
MODEL STUDY OF BREAKWATER LOCATION
U. S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

MAGNITUDE AND DIRECTION OF CURRENTS AT NAVIGATION OPENING

SCALES



NOTE: WIDTH OF NAVIGATION OPENING EQUALS 500 FT.
CURRENT DIRECTION AND MAGNITUDE MEASURED
WITHOUT WAVE ACTION.



NOTE: WIDTH OF NAVIGATION OPENING EQUALS 750 FT.
CURRENT DIRECTION AND MAGNITUDE MEASURED
WITHOUT WAVE ACTION.

LEGEND

- BREAKWATER LOCATIONS
- ← 2.2 — EBB TIDE CURRENT - FEET
PER SECOND PROTOTYPE

MODEL STUDY OF BREAKWATER LOCATION
U.S. NAVAL AIR STATION
ALAMEDA, CALIFORNIA

MAGNITUDE AND DIRECTION OF CURRENTS AT NAVIGATION OPENING

